RISK ANALYSIS IN
MANAGEMENT PLANNING AND PROJECT CONTROL

(Probabilistic techniques are applied to the estimation, planning, forecasting and control of large capital projects to ascertain and reduce the degree of inherent risk and uncertainty)

by

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There is no treasure like knowledge

Ali (Radiallāhu Taala'anhu)

<u>Dedicated</u>

To all those who have influenced me most

my parents

my elder brother

my wife

my teachers

friends and colleagues

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ABSTRACT

Effective estimation, planning, and control of the functions, operations, and resources of a project are among the most challenging tasks faced by the management of today's engineering and construction organisations. The increase in size and complexity of modern projects demand a sound organisational structure and a rational approach.

The main objectives of the present study are two-fold. Firstly to report and critically review theoretical and practical developments of different aspects of the management of engineering and construction projects. Secondly to further develop conceptual, practical techniques and processes; also to provide guidelines to make more effective use of resources and systems. To achieve these objectives the present research was carried out in close collaboration with various industrial organisations.

The current literature on project management is critically examined from the point of view of project cost estimation, planning and control. Various existing and recommended procedures, approaches and techniques are reviewd with particular emphasis on using probabilistic techniques.

As the problems of scale are increasing, progressively more industries are adopting systems and project management approaches. Problems, deficiencies and gaps in the existing systems are identified. An analysis of a questionnaire survey on Systems Gaps is carried out and the results of the analysis are reported.

S-curves (or progress curves) are widely used in the planning and control of cost, time and resources. A mathematical model for the S-curve is adopted for this purpose. Expenditure data on a number of recent projects is analysed and fitted to two S-curve models suggested by Keller-Singh and the Department of Health and Social Security (D.H.S.S.). A comparative study of the models is carried out. A set of standard parameters for the models is obtained and the predicting accuracy of these models for forecasting expenditure for future similar projects investigated.

Quantification aspects of risk involved with the completion time of a project are studied. A number of stochastic distributions are fitted for this purpose to the programmed and actual durations for the different activities of a housing project. The maximum likelihood method is used for the estimation of parameters of the fitted distributions.

Due to the increasing use of indices in the construction industry, building cost and tender price indices, their application, limitations and methods of formation are discussed. Box-Jenkins models are employed to study past behaviour and to forecast future trends for labour, materials and building cost indices.

Finally, general conclusions derived from the present research are summarised and areas requiring further research are proposed.

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CHAPTER 1

INTRODUCTION

In this chapter the objectives and scope of the study are described, and the importance of the study is discussed. A plan of the thesis is also given.

1.1 Introduction

During the last two decades, there has been a marked growth in both the size and complexity of engineering and construction projects such as steel mills, chemical plants, refineries, power-generation stations, hydroelectric plants, dams, bridges, mineral resource developments, and other industrial, civil and defence installations. Fig. 1.1 (Paulson, 1975) gives a bird eye view of the challenges faced by today's construction projects. To successfully complete these ventures under the constraints of time, cost and quality (and/or performance), the importance of effective management, planning and control is obvious because of the risks associated with the above mentioned three parameters of cost, time and quality.

With the increase in size and complexity of the construction and engineering projects, there have been significant developments in the corresponding organization structures, techniques, methods and processes to accomplish these ventures successfully.

These developments can be classified as

(a) conceptual : the long-overdue recognition of the need for a project management organisation.

(b) Practical : greater realisation of the need for more effective estimation, planning and control techniques.

1.2 Objectives of Study

The main objectives of the present study are twofold, firstly to report and critically review the theoretical and practical developments during the last two decades regarding the management, planning and control of large engineering and construction projects, and secondly to further develop conceptual and practical techniques and processes on these aspects of project management in order to make more effective use of resources (man, machine, money, materials, etc.) and systems.

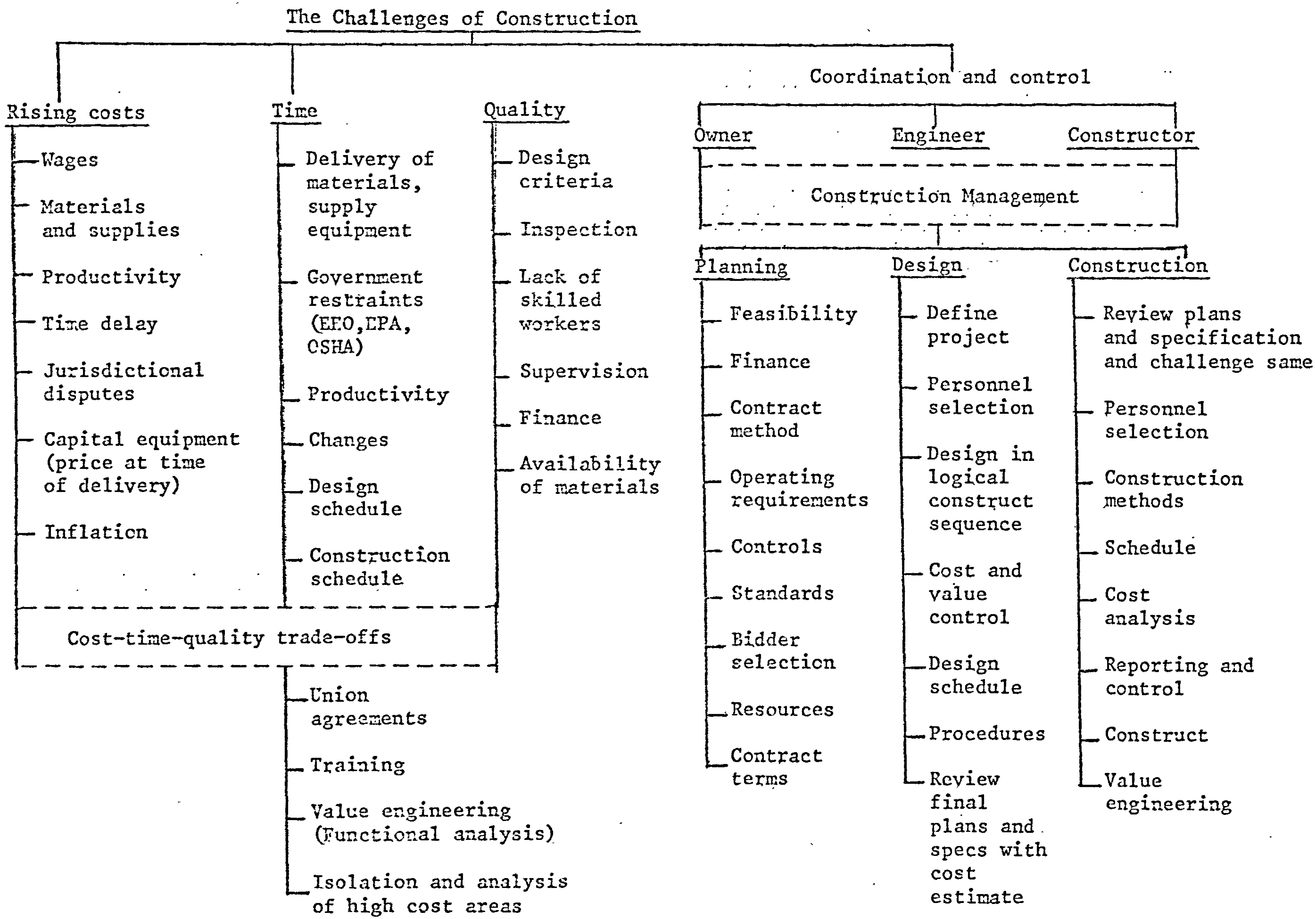

Figure 1.1 The Challenges of construction

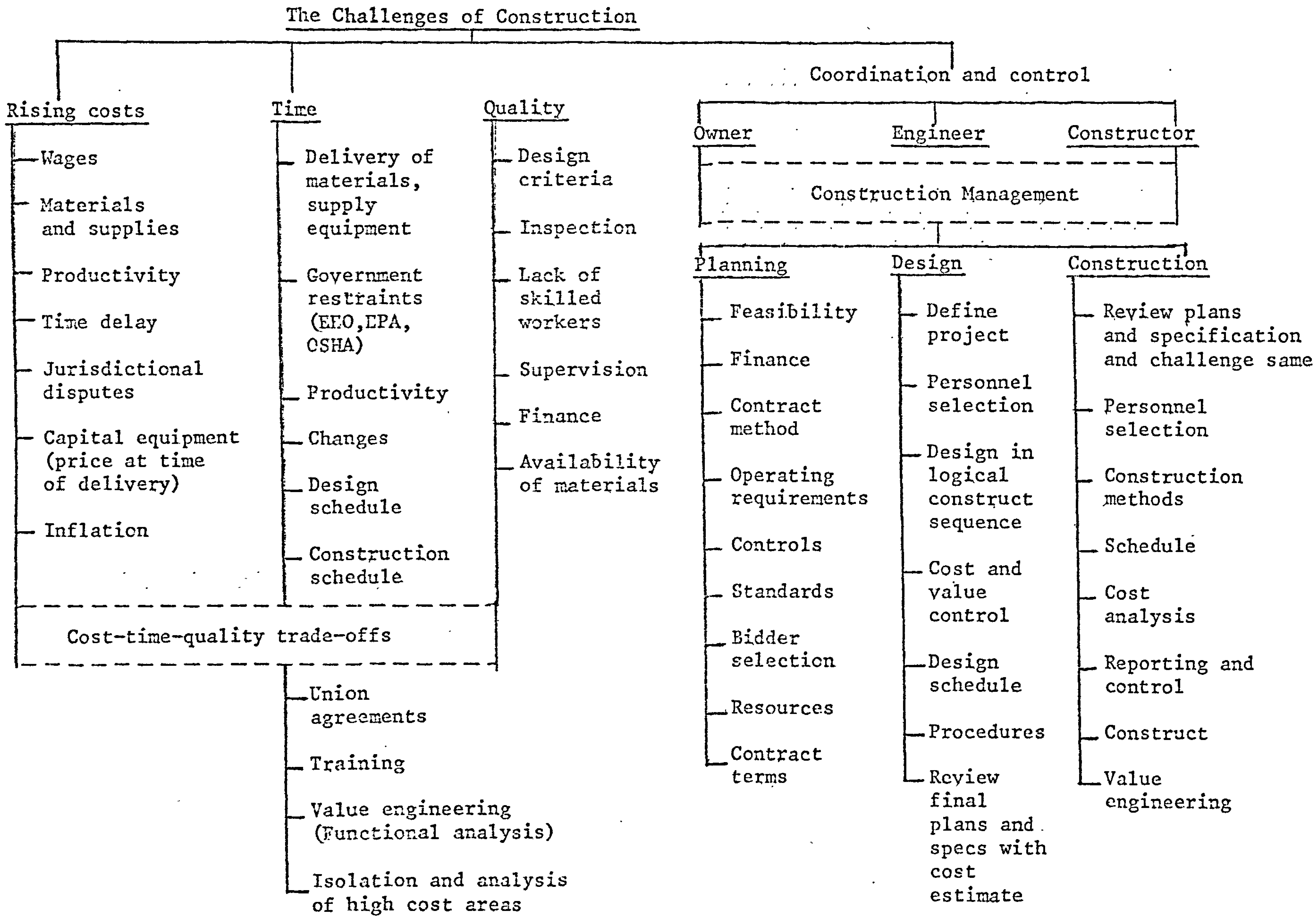

Figure 1.1 The Challenges of construction

1.3 Importance of Topic

The above methods, although evolved over many years, form an interlocking and interacting overall management system. By the application of these methods within a dynamic overall-system concept, it is possible to successfully complete large complex projects within minimum cost, time and quality constraints.

These methods, developed particularly for large projects, when sensibly applied, are also valuable for other, smaller work. Organizations of any size and in many fields, therefore, can successfully utilize these basic principles and techniques of management, planning, estimation,forecasting and control - the principles and techniques which have been tested on a large scale for engineering and construction projects and widely reported in the literature.

1.4 Scope of the Study

The present research has been carried out in close collaboration with the engineering and construction industry. This collaboration has helped the understanding of inherent problems and deficiencies associated with existing organisation structures and with the existing techniques being utilized in the industry for the management, estimation, planning, forecasting and control of projects. It has also helped to identify areas required further investigation and developments. Another major advantage of this collaborated research was the immediate application of the developed techniques in a practical working environment and feedback regarding the applicability, limitations and/or benefits of the techniques.

In the remaining part of this chapter some basic ideas and approaches related to the topic are discussed and a plan of the thesis is presented.

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1.5 Management

Management may be defined as a process of establishing and organizing objectives, planning, scheduling and controlling resources (men, money, machine and materials) to accomplish them. Effective management organisation set-up is the first step for achieving these goals. As rightly identified by Cleland and King (1975):

"Organizational theory and management principles provide a basic guide for planning, organizing, and controlling the human and nonhuman resources involved. The truly significant result of this integration is the realisation that the systems aspects of management cannot be separated from foundations of traditional management theory.

Taken together, the traditional and modern concepts of planning and execution form an integrated whole. Management relationships and problems change as new theories and techniques are formulated. Principles of management appropriate in one environment may not be appropriate in another. No doubt, new ideas of management will evolve as we become more knowledgeable concerning the structure and dynamics of our industrial society.

The modern manager must maintain his pragmatism and utilize both traditional and modern thinking in making and executing his decisions in this environment of high risk and uncertainty. His management philosophy must change with the patterns in management, for only a management philosophy which is developed on such a base is adequate for today's complex management tasks."

Snowdon (1977) has discussed various types of organisation structures. Pilcher (1976) has discussed advantages and disadvantages of functional and project management organisations. Due to the increase in size and complexity of modern projects, more industries are using project management and systems approaches to make effective use of resources and to control the complex operations of today's large projects.

Project management is an all-embracing term, covering the management of every detail of a project from its inception to its completion. A project may be divided into three main phases and correspondingly three management activities may be associated with them.

(1) Establishment of Concept and Feasibility (estimation)

(2) Design and project definition (planning)

(3) Execution, construction and full development (control)

At the concept of feasibility stage objectives of the project, form of contract, and rough estimates of time, cost and resources are established.

In the design stage, the project objectives and estimates of time, cost and resources are refined and expressed in greater detail. Usually this is done by drawing network plans, identifying critical activities, and assigning time, cost and resources to these activities. Setting objectives and methods to achieve them.

It is during the execution/construction phase, that actual problems are encountered. This requies an effective organisation system and control procedures and techniques to keep an eye on the achievements with regard to cost, time and quality.

1.6 Selecting a Contract Type

Extreme care is needed in selecting a contract type, as the non-compliance with contract conditions can lead to heavy financial losses and long legal battles between the parties. Ambiguous contract conditions or form of a contract may cause coat overruns, delays or problems. Khurbanda et al (1980) has reported that a well established contracting firm was completely wiped out from the business due to heavy cost-overruns (cause seems to be poor estimation, planning, control and ambiguous contract conditions). The amount of information available for controlling a project is a function of number of options open to the clients and contractors and depending on the type of contract, as shown in figure 1.2 taken from Barnes (1975). At one extreme, a client who negotiates a fixed price contract is able to exercise any of his options only at the negotiating stage; thereafter, when the contract is signed he has no option left and therefore he does not need a control system. At the other extreme, a client who authorizes a cost plus contract can exercise control if it is possible to vary the rate of usage of resources on a project.

Ahuja (1976) has provided a guide for selecting a contract type given in Appendix A. It contains contract types, explains the design, drawings and specification requirements, principal applications, advantages, and disadvantages of each contract type. Comments relating to change orders, claims, and contract administration are also included. The table provides a guide to help draw a distinction between different types of contracts and to identify the most suitable contract type available according to the requirements of a particular project.

1.7 Risk and Uncertainty

A risk may be defined as a situation where the outcome of an event is not known with certainty but where it is possible to ascertain :-

(i) The number of alternative possible outcomes.

(ii) The probability of occurrence of each outcome.

(iii) The magnitude of each outcome.

A position of uncertainty can be defined as a situation where the outcome of an event is not known with certainty, and where it is not possible to ascertain all three of the risk criteria listed.

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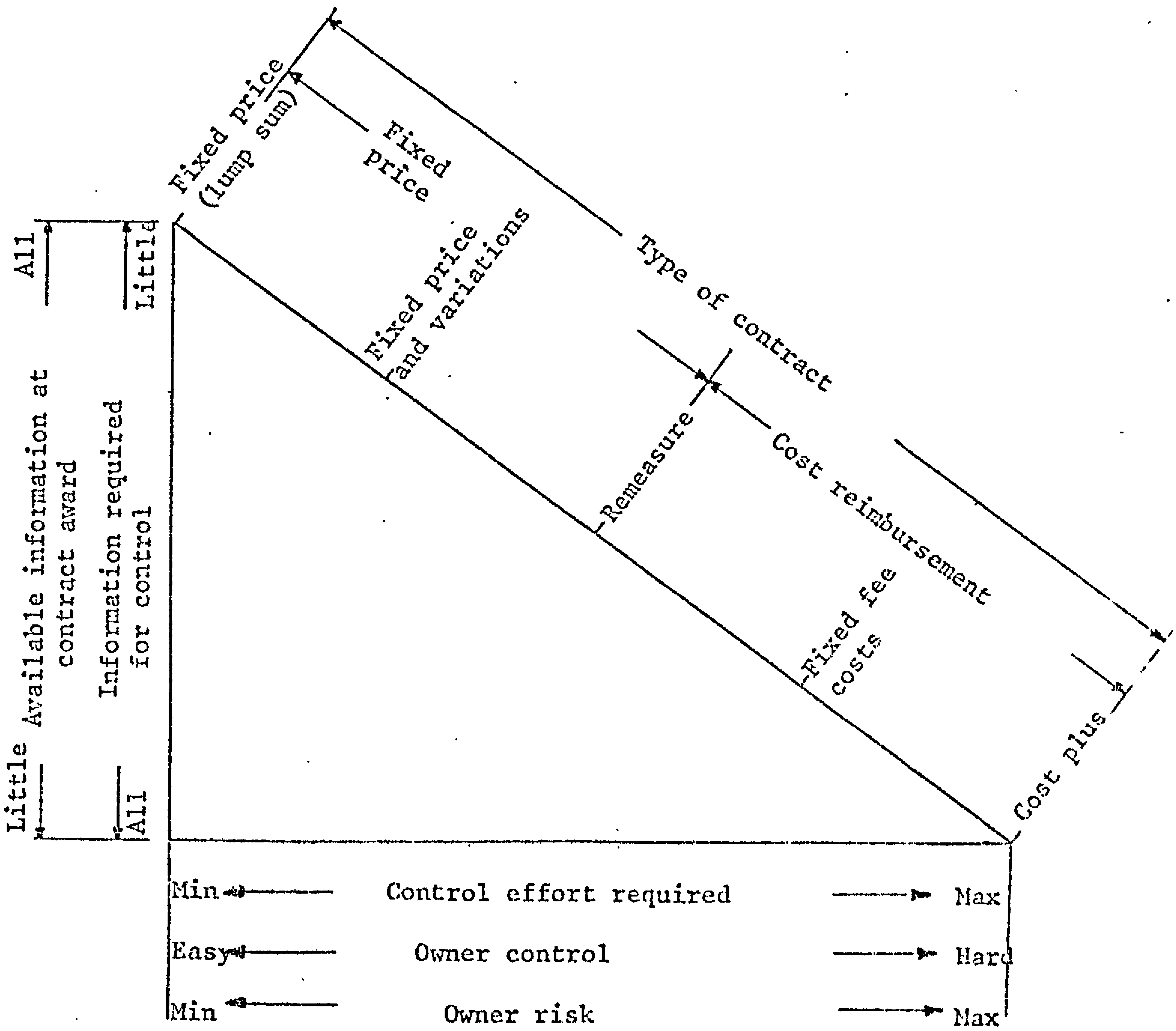

Figure 1.2 Trade-off between information, risk and control

In many situations the two definitions overlap. This often applies in long term investment decisions where the early years may be considered under the heading of risk but where later years may well be subject to uncertainty.

Probability theory lies at the heart of the evaluation of risk and uncertainty. In many simple cases standard deviations and variances provide a good measure for the assessment of risk and uncertainty.

Projects are high risk enterprises, particularly construction projects. Most projects contain some elements of risks and uncertainty associated with time, cost, resources and operations. Krantz (1976) has identified a number of uncertainties associated with a project:

- uncertainty, attendant political or other governmental decisions or actions
- uncertainty regarding rate of technological development or likelihood of technical targets being met
- uncertainty in the nature or scope of work to be performed
- variability in work performance
- delays in obtaining top management approvals
- variability in weather impact on exposed work
- uncertainty in delivery dates for material or equipment
- possibilities of design recycling
- uncertainty regarding rate of cost escalation
- possibilities of test failures necessitating remedial work (possibly even re-design).

Conclusions drawn from a study of current literature and supported by a recent survey (by INTERNET (U.K.) reported in Chapter Three) show that very few organisations use Risk Analysis techniques in their planning and control operations.

Most of the literature on Risk and Uncertainty is confined to the application of risk analysis techniques to investment analysis and appraisal. (Sykes, Hertz, Wagle, Hillier, Pouliquen, and Reutlinger). Movenzadeh & Rossow (1977) have discussed in detail risks in the construction industry and the various approaches such as Discounted Cash flow techniques, Statistical Decision Analysis and Network techniques which may be used to analyse the risks at company and project level.

Realizing the need for applying risk analysis techniques in the planning and control of projects, research has been directed in this dimension at the Postgraduate School of Industrial Technology. Keller (1975), Supriyasilp (1975), Gupta (1976), Singh (1978), Sehgal (1978), Fatmighomi (1980), Roosta (1979), Sanamrad (1980) and Saavedra (1981) have carried out research on the application of risk analysis techniques to various aspects of Project Management.

In the present research, wherever possible and applicable, consideration has been given to develop methods to reduce the inherent risk and uncertainty in the estimation, planning, forecasting and control functions of project management. Probabilistic techniques reported in the current literature are also critically reviewed.

1.8 Presentation of Thesis

Chapter two of the thesis contains a comprehensive survey of the various existing and recommended procedures, approaches and techniques for the estimation, planning and control of large engineering and construction projects. Consideration has been given to the probabilistic approaches and techniques on these aspects of project management.

Despite various organisation structures and techniques developed to accomplish large projects successfully, many projects are still controlled less effectively than they could be. In Chapter Three, the current literature on Project Management is critically reviewed and the problems and deficiencies of the existing systems are discussed. Realising the need for a detailed study to find out reasons for the gaps and deficiencies in the existing systems The Association of Project Managers (INTERNET U.K.) set up a working party for this purpose. The findings of the working party are reported. To further analyse the causes and to propose solutions, the working party prepared a questionnaire on the current practices of modern management techniques in the U.K. The questionnaire was sent to a number of organisations in the U.K. The author has analysed the replies of the survey. Highlights and details of the results are reported and discussed in this chapter.

Estimation, planning and control aspects of project management is discussed in Chapter two. In Chapter four an S-curve model originally proposed by Keller is used for this purpose. The model is compared with the one proposed by the Department of Health and Social Security (D.H.S.S.). Both the models are fitted to the actual data for more than 20 projects. The predicting accuracy of the two models is compared and a set of standard parameters for the two models is obtained.

In chapter five quantification aspects of risk involved with the completion of a project are discussed. A number of statistical distributions are fitted for this purpose to the programmed and actual durations for the different activities of a repetitive housing project. Maximum likelihood methods are used for the estimation of parameters of the fitted distributions.

Due to the increased use of building cost and tender price indices for approximate initial cost estimation of projects, the uses of these indices, limitations and methods of formation are discussed in Chapter six. Box-Jenkins models are developed to study the past behaviour and to forecast the future trends for labour, materials, building cost and tender price indices.

Finally, Chapter seven contains general conclusions drawn through the present research. Areas requiring further research are proposed.

CHAPTER 2

PROJECT MANAGEMENT - BASIC CONCEPTS AND PRINCIPLES

This chapter outlines the modern basic concepts and principles for the estimation, planning and control of large engineering and construction projects. The approaches and procedures, in this regard, reported in the current literature are critically reviewed. Guidelines are provided for effective techniques and procedures which can be utlised for this purpose.

2.0 Introduction

In recent years the increase in size and complexity of engineering and construction projects have led to the seeking of effective means of estimation, planning, managing and controlling these ventures in the most economical way within reasonable time and adequate quality constraint. To achieve these objectives it is necessary to have full understanding of the estimation, planning and control processes and all the practical tools.

These three facets are highly interrelated and interdependent, each focusing on different aspects of an overall management planning and control process.

To find out reasons why there is a continuous need for more advanced sophisticated techniques and processes for the estimation, planning and control of complex engineering projects, a few quotations from the recent literature are presented.

Krantz (1976) has reported "Public visibility has highlighted an increasing number of near-catastrophic overruns on large-scale undertakings in both government and private sectors, while countless projects of lesser scope have suffered similar fates known perhaps only to the investors and operators involved. A growing frequency of these near-catastrophes, in conjunction with an increasingly constraining economic climate, has brought about considerable research into both the causes for project overruns and the project management process, itself."

Furthermore, analyzing the causes of these overruns he wrote "It is true that much of the failure can be attributed to unfavourable elements in project environment such as lack of top management support, ineffective project organization, improper designation of authority and responsibility, and ineffectual communication and information flow. But even given a favourable management environment, there is substantial reason to believe that commonly used schedule and cost projection and control techniques are not only ineffective but may also be major contribution factors to project overruns. The basic problem lies in their failure to come to terms with variability and uncertainty. Where these factors are not accounted for in project analyses, schedules and budget targets tend to be optimistic, the degree of optimism for individual projects varying from 10% to 50% or more. In other words, overruns are built into project plans, schedules and budgets by the single-value analysis techniques, themselves."

For these reasons probabilistic techniques are given particular attention in this and subsequent chapters. It is hoped that the techniques and procedures reported here would help management to control the time delays and cost overruns. Another major area of improvement is concerned with the organization structure. By effective management and using sophisticated techniques considerable savings can be obtained. An example is quoted from Weinburge (1978):

"Dependable results over the last 10 - 15 years in the U.S.A. Europe and other construction markets have indicated that using the time/cost control systems effectively, projects have been designed and constructed in from 25% - 50% less time and for 5 - 15% less cost than directly comparable projects using more traditional methods. During periods of rapidly changing costs and economic uncertainty cost savings due to time savings are very effective. The monetary savings have been net savings after construction management fees, and were obtained without sacrificing owner's functional requirements, whether in size, specification or quality. The savings are due to more skilled design and management".

Realising the need for improved methods to plan and control engineering and construction projects Paulson (1976) reported "In recent years, construction organizations, including designers,

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contractors, and owner agencies, have increasingly found that their past and present modes of operation are becoming more and more inadequate for the complex large-scale engineered construction projects of today, let alone the future.

The potential benefits from improved methods of accomplishing the engineering planning and control of today's projects are worth seeking. For example, knowledgeable resources have estimated that the costs of delay on a major two-unit nuclear power plant exceed $200,000/day. Consider this in the context of current 10-year to 11-year design and construction times for such projects, and multiply it by the 50-plus power plants in the active concept, design, or construction phases at any one time. The potential savings thus derived are just for one industry. Similar conclusions may be drawn when looking at urban rapid transit systems, refinery and chemical plants, pipelines, mineral resource developments, and the design and construction of projects to implement the advanced technologies -----

----- Both improved methods and the better application of existing principles are needed in the planning and control of engineering and construction projects -----

----- The difficulties or planning and controlling large engineering-construction projects are real and they are increasing in complexity. The need for research is great."

An accurate estimate of project costs, time, and resources provides a proper basis for planning and control of a project. Effective and meaningful planning and control must begin before the design stage and is maintained by proper estimation. Estimation is closely linked with design and forms the basis for future management, planning and control.

This chapter outlines the modern basic concepts and principles of

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estimation, planning and control for large engineering (such as nuclear power plants, satellite projects, refinery and chemical plants etc.) and construction projects. These concepts and principles can be applied with equal success to small projects in other fields such as a housing scheme. The most widely used techniques are reviewed critically, and their limitations and/or benefits are discussed. Most of the techniques used are based on deterministic input of the decision variables, whereas in reality there are many uncertainties associated with these inputs. Consideration has been given to the Risk and Uncertainty associated with a project by introducing and reviewing Probabilistic techniques.

2.1 Estimation

General Considerations :

Estimation of time, cost and resources is the first stage in the treatment of a project. The basic information in estimation are the descriptions and specification of the project. Usually a preliminary network plan is made. On the basis of these plans and specifications and using past experience (historical records of similar past projects) and expectation of future events, the estimates of time, cost and resources are made for a new project or facility.

Later, when the project starts, the actual values are collected and compared with the estimate. If necessary new projections are made and estimates are modified for the remaining parts of the project. In this way these estimates are used to compare the performance with the original estimates.

2.1.1 Need for Estimates

Erikson and Boyer (1976) commenting on the need for estimates wrote "On a broader scale than contractors bidding a construction project, good estimates are necessary for others such as owners to allocate resources to projects that promise the most benefit per unit investment. The term "owners" in this context may be private individuals or corporations, or government agencies representing society as a whole. Engineers, architects, or other design professionals are in need of good estimating capabilities to facilitate design within an owner's cost guidelines and to compare possible design alternatives. Finally, the contractor has a tremendous need for good estimates because he is often guaranteeing a maximum cost to the owner, whether it be a lump sum or unit price bid". For this and other reasons the need for better estimates is inevitable.

2.1.2 Uses of Estimates

On the use of estimates Vergara and Boyer (1974) reported "Estimates are also used in preliminary stages of the project. The contractor forecasts future cash flows on the basis of the estimates of cost, the schedule of operations for the project, and the expected progress payments. In that way he is able to foresee the financial requirements and take the necessary steps so that loans can be obtained on time".

2.1.3 Accuracy of Estimates

There are numerous methods for preparing estimates depending upon the degree of accuracy desired. Each method has its appropriate applications, limitations and/or benefits. Some methods give a rough estimate of the costs and some give more precise costs. Some methods are used to find estimates that serve as check points to more precise procedures. The precision of the estimates depends not only on the method but on the type of work and on the intended use of the estimate. Of the conventional methods the most precise is to make a detailed estimate of all quantities of labour, material, and equipment required for the project. Frequently, time constraints require the use of faster methods in which precision is sacrificed for speed and facility of preparation.

2.1.4 Uncertainties in Estimates

In reality a number of uncertainties are associated with different elements of a project. Vergara and Boyer (1974) have identified uncertainties in estimates :

"In preparing an estimate the number of assumptions required are such that no method may be considered perfect. Other factors that further complicate the preparation of estimates are their dynamic and uncertain nature. They are dynamic because costs are changing constantly and must continually be updated. Among the uncertainties that influence construction costs are : (1) Weather conditions; (2) political as well as economical variations; (3) changing nature of construction technology and costs; (4) different maintenance technology; (5) differences in labour productivity; (6) material and equipment availability; (7) construction delays; (8) supervision policies; and (9) construction methods, etc. To arrive at an estimate, the estimator has to evaluate these factors and their influence on actual costs. Since many of these factors have random variation it is found in general that estimates vary greatly from actual costs."

2.1.5 Desiderata of Estimating Procedure

In increasing the level of details in the preparation of estimates the constructor finds not only time constraints but also cost constraints. The cost of preparing an estimate increases with the level of detail. Sometimes having a more accurate estimate means that the contractor will have to increase his bid to cover increased estimating costs. In competitive environment he would then have less probability of becoming the winner. If the contractor prefers to decrease his markup he increases the risk of incurring a loss on the project. A tradeoff must be made between having a more accurate estimate, which decreases risk and reducing the markup, which increases the risk of sustaining a loss.

Many factors have to be considered in the determination of the optimum level of detail. Among them we may cite the type of job, the amount of competition expected, the quality and amount of information available on the project (plans and specifications), the time available for preparing the estimates, past experience, etc.

2.2 Methods of Estimation

Usually, estimates are required in the early stages of a project, when enough details or specifications are not available. More refined estimates can be obtained as the project proceeds and more details are available. According to Peart's (1971) experience, "such estimates are of particular value when they are prepared according to PERT techniques." He has presented two approaches for estimation of time, cost and resources for a project. The first approach is applicable to small projects and the second approach is applicable to either major projects or multiple-project situations.

Simplified Procedure

1. Prepare a simple PERT network, showing the activities and their interdependencies.
2. Allocate manpower requirements to the PERT activities, based on experience or historical records of similar work.
3. Raw materials, purchased components and any other similar items may be listed and costed and allocated to the PERT activities.
4. The activity times will be determined by assessing the availability of men in relation to the manpower requirements determined above. These times will be inserted on the PERT network.
5. Labour resources may be reallocated in order to shorten the critical path to the desired maximum duration.
6. The estimated total project duration will be calculated by making a "forward pass" through the network.
7. Having obtained an acceptable estimate of the project duration, the costs of the various activities may be summed to produce an estimate of the total cost of the project.

8. The tender price will then be computed by adding contingency allowances, overhead costs and a profit margin to the basic cost determined.

For a relatively simple project, the above information can usually be contained in no more than three documents. First, the PERT network can contain the details of the manpower requirements and durations of the various activities. Secondly, the project costs can be collated on a cost summary sheet. Thirdly, commercial information, remarks and other relevant data can be set out on a tender submission record form.

Composite Procedure

In concept and basic principles the composite procedure follows the simplified procedure described above. But due to the increase of size and complexity of the project the following points are worth giving more attention :

The PERT Network

The information contained on the network should include activity descriptions, durations and resource requirements as required for the simplified procedure. In addition, it may be desirable to show the estimated earliest and latest event times, the critical path, and responsibility codes against individual activities. In many situations, it should be possible to sub-divide the project into work packages.

Materials and expenses record

The purpose of the materials and expenses record is to show details of all purchased raw materials, components, and sub-contracted work as well as anticipated contingency expenses.

Assuming that the estimate is broken down into work packages or similar sub-divisions, it may be desirable to collate the labour, materials and other costs on to work package summaries.

Estimation of Project Costs

Barrie and Paulson (1978) have categorised different types of estimates from less detailed to more accurate as the project evolves. These are

1. Conceptual and Preliminary estimates
2. Detailed estimates
3. Definitive estimates.

2.2.1 Preliminary Estimates

Preliminary estimates assist the overall cost-control program by serving as the first check against the budget, and by indicating cost overruns early enough to review the design for possible alternates. Since preliminary estimates are made prior to the completion of detail drawings, the margin for error is usually greater than for fair-cost estimates.

According to Barrie and Paulson (1978), most of the existing conceptual and preliminary estimating methods fall into one or more of the following categories.

1. Cost indices
2. Cost-capacity factors
3. Component ratios
4. Parameter costs.

2.2.1.1 Cost Indices

Cost indices show changes in cost over time. In some cases, these may reflect changes in technology, methods, productivity and inflationary trends. Generally they are applied during the construction phase of the projects, though they can also be used for whole duration of the project. Many of these indices are published in the technical press. In the U.S.A. the "Quarterly Cost Roundup", published by the Engineering News-Record, lists over a dozen of these indices including its own well-known "Construction Cost Index" and "Building Cost Index". The U.K. Department of Environment (DOE) publishes various indices in their Housing and Construction Statistics. Several private firms also prepare indices for their own use, Davis, Belfield and Everest, a chartered quantity surveyor firm, publish their Building Cost and Tender price indices in a technical journal (D.B. & E. 1975). Before applying cost indices, it is important to understand how they are derived and their limitations.

These limitations become evident when one compares advantages and disadvantages of different types of indices. For example, the indices based on input components do not consider factors such as productivity, changes in technology, and competitiveness of contractors. These factors are reflected to some extent in indices based on project outputs, or completed structures. On the other hand, the output type of indices are usually much more narrow in scope, and it is difficult to interpret one based on, say, commercial office buildings, to apply it to another type of work, such as a concrete dam. The input type of indices is much more general and can thus be applied to a broader range of construction projects. In both indices, it is important to recognize their geographic and demographic bases. Both prices and productivity can vary radically around the country and around the world; competitive market conditions for suppliers and contractors can be strong in one type of construction, such as industrial, at the same time that they are weak in another, say building.

For these and many other reasons, owners, designers, contractors and construction managers must use careful judgement and draw upon well-documented personal experience before applying any type of index for the purpose of conceptual estimating. Successful firms maintain their own records and do their own studies as well as use published sources. Properly applied, however, such indices can yield accuracies within 20 to 30 percent of actual costs and can provide this information with almost negligible time and effort. Such information can be valuable for policy and planning decisions early in the life of a project.

Construction cost indices are discussed in more detail in Chapter 6.

2.2.1.2 Cost-Capacity Factor

Cost-capacity factors show changes in size, scope, or capacity of projects of similar types. The cost-capacity factor may be represented by the following equation :

$$C_2 = C_1 \left(\frac{Q_2}{Q_1}\right)^x$$

where

C_2 = estimated cost of new facility of capacity Q_2

C_1 = known cost of facility of capacity Q_1

and the exponent x = the cost-capacity factor for this type of work.

The exponents represented by x are empirically derived factors based on well-documented historical records for different kinds of projects. The capacities, represented by Q, are some parameter that reasonably reflects the size of the facility, such as maximum barrels per day produced by a refinery or tons of steel per day produced by a steel mill operating at capacity. In a structure such as a warehouse, gross floor area or enclosed volume might be a reasonable measure of capacity.

Cost-capacity factors have been most widely used in the petrochemical sector of the industrial construction industry. The "sixtenths factor rule" (x = 0.6) is typical and applies fairly accurately to some types of plants (such as nuclear power plants).

2.2.1.3 Component Ratios

During engineering and design progress, more information became available about a project and its elements. Once the size and type of major items of installed equipment are identified, the designer or professional construction manager would be in a position to assess price quotations from the manufacturers of these components. Examples of equipment or plant components include compressors, pumps, furnaces, refrigeration units, belt conveyors, and turbine generators. Given good price quotations, designers and constructors in many sectors of industry, have good historical documentation and analytical techniques that enable them to improve the accuracy of their earlier conceptual estimates. To do this they use techniques such as "equipment-installation-cost-ratios" or "plant-cost-ratios". These both are usually referred to as "Component ratios".

The first approach, equipment cost ratios, multiplies the purchase cost of the equipment by an empirically determined factor to estimate the installation cost of that equipment, including shipping, erection, labour, and ancillary fittings and supplies.

With good records to base them on, this type of estimate can be accurate to within 10 to 20 percent of final costs.

Plant Cost ratios, use equipment-vendor-price-quotations as a basis for determining the cost of the whole constructed facility. Two approaches can be used. In the first, the estimator adds the costs of all major items of equipment, and then multiplies this sum by a single ratio found to be appropriate for the type of project being constructed.

A variation on the plant cost ratio takes the cost of each major item of equipment separately, multiplies by its own ratio, then takes the sum of the factored components. This approach allows the estimator to apply at a more detailed level judgement. This assumes, of course, that good historical data are available for developing the individual factors for each item of equipment.

2.2.1.4 Parameter Costs

Estimates based on parameter costs are most commonly used in building construction. Engineering News-Record of U.S.A. usually publishes about five examples in each of its "Quarterly Cost Roundup" issues.

The parameter cost approach relates all costs of a project to just a few physical measures, or "parameters" that reflect the size or scope of that project. Nevertheless, with good historical records on comparable structures, parameter costing can give reasonable levels of accuracy for preliminary estimates.

This type of estimate requires at least schematic drawings sufficient for computing these few parameters.

2.2.2 Detailed Estimates

After the conceptual design has been approved and after most or all of the detail design work is completed, approximate estimates are generally supplemented by detailed estimates. These normally require a careful tabulation of all the quantities for a project or portion of the project; this is called a "quantity take off". These quantities are then multiplied by selected or developed unit costs, and the resulting sum represents the estimated direct cost of the facility. The total estimated cost of the project is obtained by the addition of indirect costs, plant and equipment, home-office overhead, profit, escalation, and contingency. Since a careful takeoff can minimize or eliminate the unknowns regarding the amount of work to be performed, the margin of errors is considerably reduced. Contingency requirements decrease since direct cost of the work is the major variable left to the estimator's judgement.

Two types of detailed estimates are common in construction industry : the fair-cost estimate and the contractor's-bid estimate.

2.2.2.1 Fair-Cost Estimates : for construction projects are best prepared from the actual bid documents (i.e. plans and specifications). They are based upon actual quantity takeoffs which are multiplied by unit prices developed for the items.

Fair cost estimates are sometimes used for measuring job progress and for the schedule and cost control. When properly applied, it can also result in productivity evaluation, comparison with contractor estimates, and assist in continually updating estimator's knowledge and skills.

2.2.2.2 Contractor's Bid Estimate

It is based on the unit-cost system in which overall unit costs, including costs of labour, material, equipment, and overhead, are applied directly to actual quantity takeoffs. However, due to sharp price changes for all components in recent years, this method is becoming increasingly rare.

In one way, bid estimates are sometimes less detailed than fair-cost estimates since Subcontractors often account for up to 30 to 80 percent of the project.

2.2.3 Definitive Estimates

As a project evolves, initial approximate estimates become more accurate as additional information is made available. Finally, there comes a time when a definitive estimate can be prepared which can be used to forecast final project cost with greater accuracy. The margin of error associated with these estimates can be minimized through the proper addition of an evaluated contingency.

2.2.4 Probabilistic Estimation

Earlier in Section 2.1.4 it was mentioned that there are many uncertainties involved in the process of estimation. Vergara and Boyer (1974) realizing the need for a probabilistic approach to estimation reported "Construction cost estimating is normally approached in what appears to be a deterministic manner. However, implicit in the approach is the awareness that estimating is probabilistic. If contractors are to improve the quality of estimates, they must utilize methods that are consistent with their probabilistic nature. It must be accepted that estimates may vary. The objective must be, rather than seeking an exact number, trying to measure the variability of the probabilistic distribution of the estimate should be generated.

Having this possible variability of costs, the contractor will have deeper insight into the cost of the item analyzed. This enables him to better judge and weigh the risk involved and compare it with the risk he is willing to take."

Extensive work has been done on probabilistic estimating in the defense industries in U.S.A., but only a limited amount of published information is available.

Campbell (1971) has reported aprobabilistic procedure for estimating. His procedure relies heavily on the subjective evaluation of the estimator and suffers only in the precision required, five points, for establishing the probability density function of the difference between estimated and actual costs.

Hemphill (1967) has demonstrated the reliability of several methods of estimating for both building and chemical plant construction. He also delineates a probabilistic estimating system which assumes the normal probability function is applicable and the estimator is operating at a 95% confidence level when placing bounds on the estimate.

Spooner (1974) has investigated the properties of various cost distribution curves for probabilistic estimating. He has presented the probabilistic variation in the estimated cost of the project, E, as the summation of the estimates, e_i, of the costs of operations of the project, and the variance, V, as the summation of the variance, v_i, of the operations of the project

$$E = \sum_{i=1}^{n} e_i, \quad V = \sum_{i=1}^{n} v_i$$

where E = mean value of the estimated project cost;

e_i = mean value of estimate of cost of operation i;

V = variance of estimate of project cost; and

v_i = variance of estimate of cost of operation i.

Lichtenberg (1972, 1974) has presented a method for network-based planning and scheduling as well as for estimating. His approach is known as "successive estimating" or "successive planning" and is being increasingly used in Northern Europe.

Successive estimating uses statistical principles both to improve the accuracy and greatly to reduce the amount of effort required for estimating the cost of a project. In essence, the successive approach requires that an estimator not only estimate the cost for each of the elements of a project, but also assess the uncertainty associated with the estimate for each element. By expressing the elemental uncertainties as standard deviations, squaring these to get variances, then taking the square root of the sum of the variances, one can quantify the uncertainty for the project as a whole. The estimator then focuses on the element that most adversely affected the uncertainty for the project as a whole : he subdivides and analyzes that element in greater detail to reduce the uncertainty associated with it, then recomputes the variances, or uncertainty, for the project as a whole. This process is repeated until either the estimator is satisfied with the level of accuracy of the whole estimate, or the estimate reaches an unreducible level of uncertainty about which the estimator can do nothing.

Vergara and Boyer (1974) have presented a probabilistic approach to estimating and cost control. The essence of their method is that usually there are some items in the project that if further analyzed will increase the quality of the total estimate more than others. They have developed a system which identifies significant items which are further analyzed to produce a substantial decrease in the uncertainties involved with the total estimate. The project is divided into a number of operations and a probability distribution is found for the cost of each operation. The probability distribution for each operation might be defined using an expected or most likely value, an optimistic value, and a pessimistic value. In the generation of the probability distribution the estimator makes use of past data, any known trend, and the results of his analysis. If enough information is not available, the estimator needs to apply his own judgement and develop subjective estimates of the cost. For each probability distribution the mean or expected value, variance, and the coefficient of variance may be defined. Then characteristics of the probability distribution for each operation are evaluated separately, and their contributions to the characteristics of the total probability distribution of the total estimate is measured. From this evaluation the items meriting further analysis are identified so that certain characteristics of the total probability distribution are improved, and the cost of the improved estimate is minimized. This process is continued as long as the value of the estimate increases. They have further proposed a method that uses a bidding strategy model and compares the expected value of bids associated with estimates having various levels of precision. Consequently, an optimal level of precision may be determined by their method. Recognizing the probabilistic nature of estimates they have added another dimension to the cost control process. As the project advances, the remaining parts are re-estimated and risk is re-evaluated.

Thurner (1978) has developed an analytical procedure for obtaining cost distribution functions.

2.2.5 Summary and Conclusion of the Section

In this section needs, uses, desired accuracy, uncertainties and methods of formation of estimates are discussed. Several approaches to estimating costs and resources for an engineering and construction project are examined.

Two procedures for estimation suggested by Peart (1971) are reported. Other methods examined include preliminary estimation techniques such as cost indices, cost-capacity factors, component ratios and parameter costs, detailed estimates such as Fair cost estimates and contractors bid estimates, and definitive estimates. Consideration has been given to the probabilistic nature of estimates. Probabilistic estimation techniques reported by Hemphill (1967), Campbell (1971), Spooner (1974), Lichtenberg (1972, 1974), and Vergara and Boyer (1974) are examined.

This section is by no means exhaustive in either content or scope as estimation is itself a wide and specialized subject on its own merit. However, some basic concepts on estimating are set forth and probabilistic aspects of estimation has been given particular consideration.

It is hoped that this section has provided some guidelines on basic concepts, principles and methods available for the purpose.

2.3 Planning

Planning is one of the major functions of management. The success of a project depends on sound planning. The plan forms the standard upon which the project control system is based and by which future performance of the project is judged. Mockler (1970) reviewing the start of art of theory and practice of planning, and looking ahead predicting the development of several trends in planning during the 1970's concluded :

"In sum, much is known about planning, but not enough corporate managers understand how to put them into practice and use sophisticated mathematical and computer tools. As a result, they are not required to direct the money spent on planning into the most effective channels. At the same time, executives frequently are unwilling to change existing organization structures and to give planners the tools they need to get the job done. As a result, the planner often works in a vaccum, acting as a sounding board for corporate management's futuristic thinking but isolated from the operating realities of the organization. Bolder and better directed experiments with planning techniques, organization, and administration are thus needed if this important function is to live up to expectations for it. We will, I believe, see many such experiments in the 1970's."

During the last decade there have been several developments in this direction. In this section consideration has been given to some of the relevant problems as identified by Mockler. Modern methods and procedures, available for accomplishing these objectives, and reported in the current literature are critically reviewed. In this section an attempt has been made to provide practical guidelines for the effective application of planning in todays competitive environment.

Duke et al (1977) commenting on the key points for success of the projects at Flour Corporation reported "A common identifiable element on most successful projects was the quality and depth of early planning by the project management group. Execution of the plan, bolstered by strong project management control over identifiable phases of the project, was another major reason why the project was successful".

Kerzner (1979) has identified four basic reasons for project planning :

To eliminate or reduce uncertainty

To improve efficiency of the operation

To obtain a better understanding of the objectives

To provide a basis for monitoring and controlling work.

Hawkins (1975) has noted the following chief advantages of planning for management :

1. The manager can plan his technical and clerical resources and ensure a balanced workload throughout the year.
2. Realistic targets can be set and performance measured against the programme.
3. As a result of better co-ordination, an improved service can be given to the client, and his special requirements, e.g. planning of work, can be accommodated.
4. It eases the dissemination of information and reduces confusion.
5. The consequences of any change can be more readily appreciated.
6. Queries regarding starting dates and duration of contract can be quickly answered.
7. It helps create a team spirit.

Kerzner (1979) has defined nine major steps which according to him must be developed during the planning phase :

1. Objectives : a goal, target or quota to be achieved by a certain time.

2. Program : The strategy to be followed and major actions to be taken in order to achieve or exceed objectives.
3. Schedule : a plan showing when individual or group activities or accomplishments will be started and/or completed.
4. Budget : planned expenditures required to achieve or exceed objectives.
5. Forecast : a projection of what will happen by a certain time.
6. Organization : design of the numbers and kinds of positions, along with corresponding duties and responsibilities, required to achieve or exceed objectives.
7. Policy : a general guide for decision-making and individual actions.
8. Procedures : a detailed method for carrying out a policy.
9. Standard : a level of individual or graoup performance defined as adequate or acceptable.

Johnson (1977) has described a ten step plan to control any project. The 10 steps, seven for planning and three for monitoring apply to any phase of a project.

1. Define tasks
2. Estimate man-days
3. Define task relationship
4. Prioritize tasks
5. Assign personnel
6. Draw Gantt Charts
7. Automated time reporting
8. Establish meaningful milestones
9. Monitor
10. Write subjective report

All effective planning involves the same basic elements which according to Woodgate (1977) may be summarised as follows.

1. A clear definition of the objective.
2. An analysis of the steps required to attain the objective.
3. An estimate of the time and effort involved in each individual step.
4. Examination of the risks involved and an assessment of the allowance necessary to cover uncertainties.
5. Calculation of the total time and cost involved.
6. Consideration of the alternative methods of reaching the objective.
7. Decision on the method to be implemented.
8. Establishment of time schedule for individual parts of the agreed plan i.e. relative to calendar time scale.

2.3.1 Planning Methods

A number of analytical and graphical techniques are used for project planning, scheduling and control of operations, time, cost and resources. Among them bar charts, progress curves or cumulative S-curves and critical path networks are widely used.

2.3.1.1 Bar Charts

The Bar Chart is a means of displaying simple activities or events plotted against time or cost. An activity is a task or closely related group of tasks whose performance contributes to completion of the overall project. Bar charts often include such items as listing of activites, activity durations, schedules dates and progress-to-date.

Advantages

Bar charts are advantageous in that they are simple to understand, and are understood by all levels of management. Also they are fairly broad planning and scheduling tools.

Limitations

Bar charts cannot show the interdependencies of the activities and therefore it is difficult to represent a network of activities. This relationship between activities is very important for controlling costs.

Bar charts cannot show the results of either an early start or a late start in activities.

The third limitation is that the Bar Chart does not show the uncertainty involved in performing the activity.

Even with these limitations, Bar Charts are useful tools for project planning. An understanding of their limitations is important to their effective and appropriate application.

2.3.1.2 Progress Curves

Progress curves, also called S curves, graphically plot cumulative progress expressed in terms of measures such as total labour cost, total money expended or quantities of work on the vertical axis against time on the horizontal axis. Actual number of units or percentages of the total can be used.

The shape of a typical S curve is obtained by calculating cumulative totals of the chosen progress measure per unit of time. On most projects, expenditures of resources per unit time tend to start slowly, build up gradually to a peak, then decrease slowly near the end. This causes the slope of the cumulative curve to start slow, increase during the middle then flatten near the top.

Like bar charts, progress curves can express some aspects of project plans. Once the project is underway, actual progress can be plotted and compared with that which was planned. It is then possible to make projections based on the slope of the actual progress curve.

A common and very effective procedure in the plotting of planned progress curves is to produce two such curves. One is determined on the basis of all project activities starting as early as possible. The other is based on all project activities starting at their late start date. When these two curves are plotted, they form a closed envelope as shown in fig. 2.1. Actual planned and reported progress most likely falls between these two extremes.

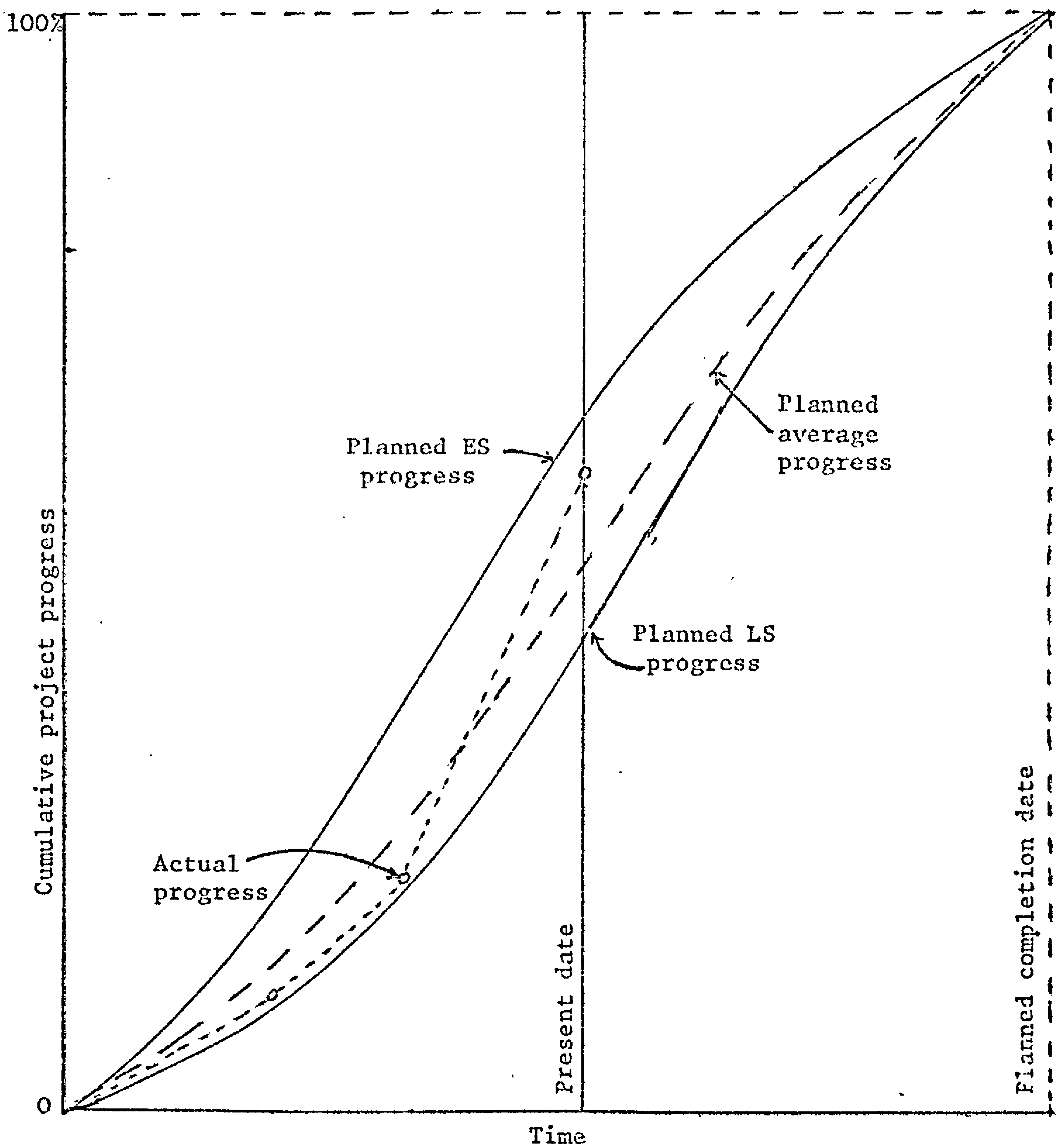


Fig. 2.1 Project progress curves

2.3.1.3 Network Analysis

Network analysis is still by far the most widely used and powerful analytical tools for the managment for planning, scheduling, evaluation, monitoring, and control of a project. According to Battersby (1970) it reduces the examination of any complex project to three essential stages :

(1) a breakdown into a set of individual activities which are subsequently arranged into a logical network;

(2) the estimation of separate activity durations, and scheduling to discover which activities control completion of the project.

(3) re-allocation of total resources to improve the schedule.

Netowrk Analysis provides a far more useful and precise approach than the bar graphs and progress curves. According to Burman (1972), Network Analysis techniques achieve their purpose in three broad steps:

(a) They present in diagrammatic form a picture of all the jobs (or activities) to be done, and of their dependency on one other. The way in which this is doene is to construct what is known as a 'network diagram' in which each job is represented by an 'arrow' or 'box' on the diagram. The way in which the arrows or boxes are linked indicates the dependencies of the jobs on each other.

(b) They consider the limitations imposed by the availability of men, machinery, money and material resources and, in view of these, estimate the time required to do each job.

(c) They apply the estimated job time to the network diagram, and then analyse the network. Analysis in this case means the calculation of the total length of time involved in each path through the network.

The longest time path through the network is known as the 'critical path' - it is the sequence of jobs which determines how soon the project may be finished. A knowledge of what jobs are on the critical path is essential. Any delay to any one of these jobs will cause the project as a whole to take longer. In other words, these jobs are 'critical' to the timely completion of the project.

2.3.1.3.1 Types of planning network

Although planning networks take many forms three basic types are in common use, the activity network, the event network and the precedence network.

Activities represent something happening and thus usually have a time duration associated with them whereas events represent a particular point in time, and do not have a time duration.

An event network identifies particular points, or milestones in the plan with arrows depicting the relationship between the events and also the estimated time duration between the events.

Activity and event networks are frequently combined to form activity/event networks, although in combined form often only important milestones are defined and unimportant are left with only an event number for identification purposes. The analysis of activity/event networks involves the same calculations as for activity only and event only networks so these three types can be conveniently considered together.

A precedence network, is an alternative form of diagram in which network activities (sometimes called work items on precedence networks) are drawn as boxes with the arrows showing the relationships (or precedences) between the various tasks. As the box represents an activity occurring over a time duration, it is necessary to define from which part of each work item the precedence arrow starts and finishes.

The precedence network more clearly identifies the work items than does the activity/event network and the convention of displaying the work item data within a rectangular box gives a clearer representation of work oriented data. Although the activity/event network contains more information about the project (as it includes event data) this shortcoming of the precedence network can be overcome by introducing 'event' boxes.

The three types of network are given in figure 2.2.

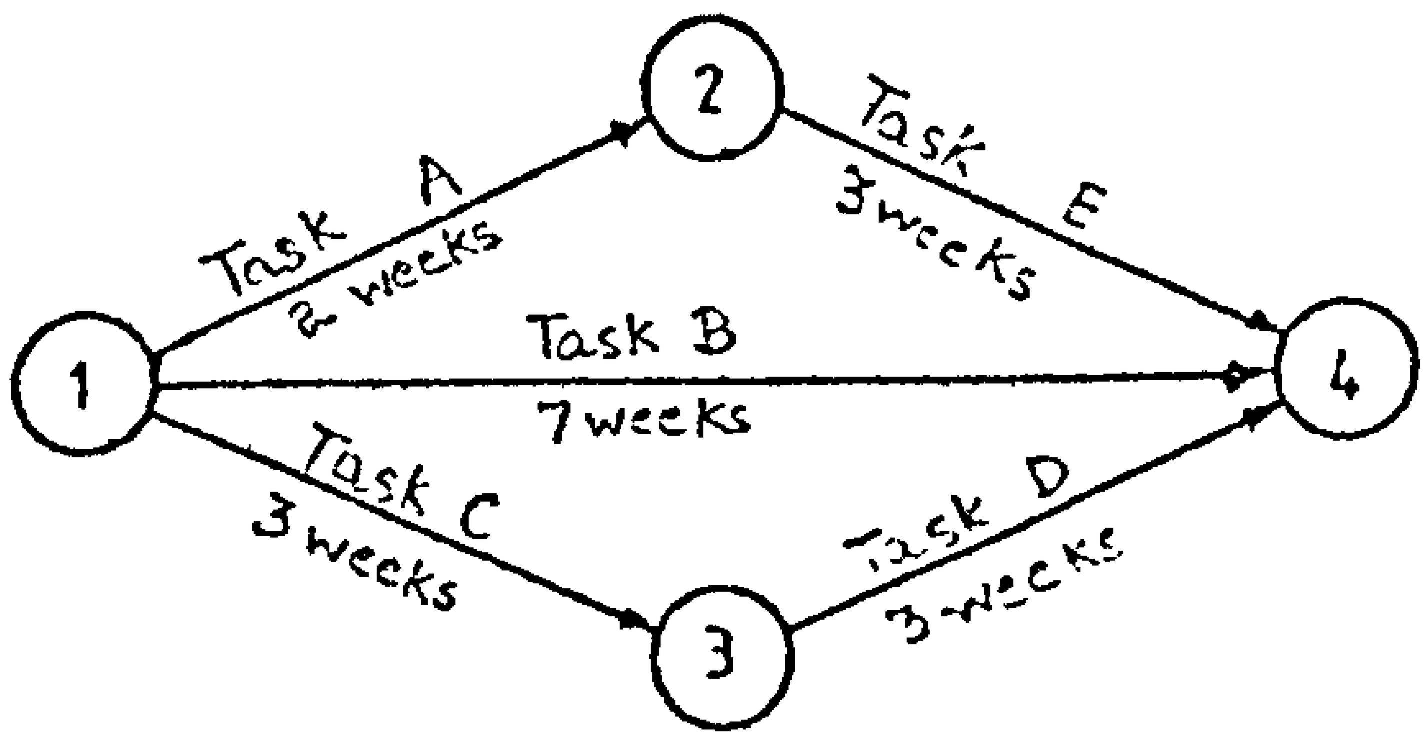
Critical Path

When the network is analysed to schedule events and activities, the overall time for the project is found. This overall project time is determined by the longest time sequence of activities and events from the beginning of the network to the end. An analysis of a network will identify the activities and events on this longest path and these constitute the critical path through the network, so called because the activities and events on this path can be considered as being 'critical' to the performance of the project. Being the longest path through the network, it also gives the minimum time in which the project can be completed.

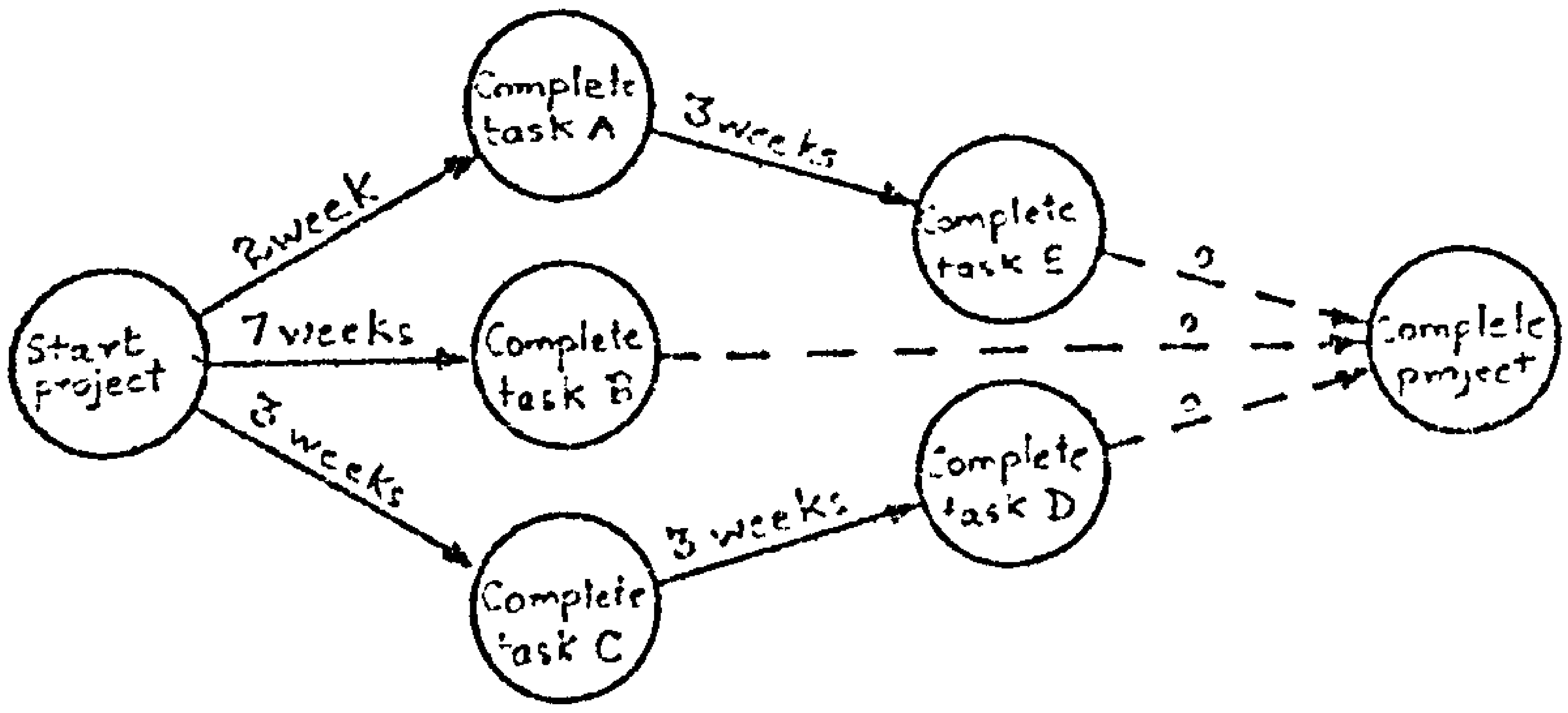
PERT and CPM

Network analysis is the generic term for several project planning methods, of which the best known are CPM (critical path method) and PERT (program evaluation and review technique). These systems were developed for application to large-scale defence projects in the U.S.A. The two procedures were developed independently of one another at about the same time in the late 1950's. The critical path method (CPM) was developed especially to improve the planning and scheduling of construction operations. The program Evaluation and Review technique (PERT) was devised to evaluate and monitor progress of the Polaris

(a) 'Activity Network



(b) Event Network



(c) Precedence Network

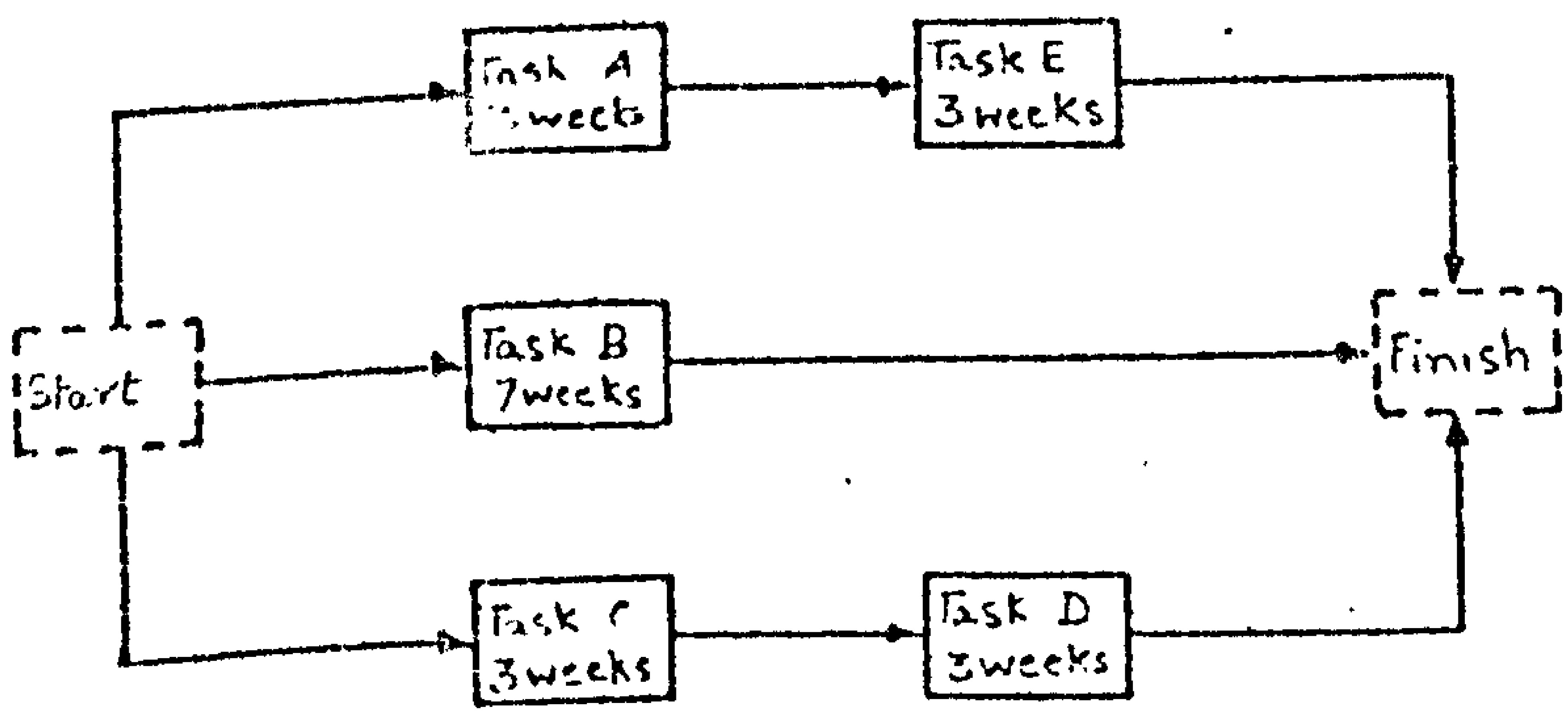


Figure 2.2 Comparison of different types of network

missile system. Although basically similar, the two methods differed in several important respects. In practice the terms CPM and PERT are loosely used and are now largely interchangeable.

The general distinction between PERT and CPM is that with PERT the results of the analyses are expressed in terms of events and the results of CPM calculations are shown in terms of activities or operations to be performed. PERT is therefore said to be event-oriented and CPM activity oriented.

CPM

CPM is based on the assumption that project duration can be shortened by applying extra cost. In this system each activity is given a normal time and normal cost (i.e. cost at normal time) and a crash time with its associated crash cost (these being the speeded-up time and cost). The CPM analysis produces least cost work schedules for each of several project durations and goes on to calculate the project duration which gives the least project cost. The analyses produced by a CPM system give information relative to network activities i.e. activity start and finish dates, floates, etc.

PERT

PERT is event-oriented but has some activity formats quite similar to CPM. The emphasis on events made PERT event-oriented, while CPM has always been activity-oriented. The PERT took the position that a single time estimate was not practical in some situations such as for research and development work. For this reason, PERT uses three time estimates : optimistic, most likely and pessimistic. The PERT assumed that these three estimates would fall on a bell-shaped Beta curve. The following formula is used to convert these three values into one value equivalent to the beta distribution :

$$t_e = \frac{a + 4m + b}{6}$$

A variance is computed for each activity; by using the standard deviation, the probability of meeting a schedule event time is calculated by the formula

$$\frac{\text{schedule date} - \text{expected date}}{\sqrt{\text{variance of event involved}}}$$

This value is then used for a statistical probability table.

The PERT time calculation is similar to the CPM event-time calculation.

Elmaghraby (1977) has reported mistakes due to PERT assumptions of Beta distribution. Fatimighomi (1980) and Sehgal (1978) have also dealt with theoretical and practical development, analysis and applications of network techniques.

GERT (Graphical Evaluation and Review technique)

CPM or Precedence network planning are best used when the operations of a project have deterministic durations. When estimates of activity durations are probabilistic, PERT networks are more useful. A common requirement to these three networking techniques is that all preceding activities or operations be completed before a node is finally reached or realized. In situations in which the realization of a node is dependent on the completion of not all, but one or more activities preceding this node and in which the performance of these activities is probabilistic, Graphical Evaluation and Review technique (GERT) is very useful. GERT determines the probability of the realization of a node based on statistical data collected through simulation. GERT is a procedure that combines the disciplines of flow graph theory, moment-generating functions, and PERT to obtain a solution to stochastic problems. It is claimed that the procedure makes it possible to analyze complex systems and problems in a less inductive manner than ever before.

A comparison of the four networking methods described is given in Table 2.1 (source : Ahuja (1976)). Table 2.1 provides a guide for the planner in deciding which network technique is most suitable for his project.

Alternative PERT/CPM Models

Because of the many advantages of PERT/time, numerous industries have found applications for this form of network. In the earlier section it was emphasised that three parameters are necessary for control of resources: time, cost and quality (or performance). With this in mind, companies began reconstructing PERT/time into PERT/cost and PERT/performance models.

PERT/cost is an extension of PERT/time and attempts to overcome the problems associated with the use of the most optimistic and most pessimistic time for estimating completion. PERT/cost can be regarded as a cost accounting network model based upon the Work Breakdown Structure and capable of being subdivided down to the lowest elements, or work packages. The advantages of PERT/Cost are that it

a) Contains all the features of PERT/time

b) Permits cost control at any WBS level

The primary reason for the development of PERT/cost was so that project managers could identify critical schedule slippages and cost overruns in time for corrective action to be taken.

Many attempts have been made to develop effective PERT/schedule models. An example of such attempts is the Accomplishment/Cost Procedure, (ACP). As described by Block, (1971)

'ACP reports cost based on schedule accomplishment, rather than on the passage of time. To determine how an uncompleted task is progressing

Features of networking methods	Networking technique: CPM	Precedence method	PERT	GERT
Emphasis on events and event times	Difficult, can be gimmicked	None	Heavy, basis of diagram	Heaviest, basis of diagram
Emphasis on activities and activity times	Moderate	Highest	Practically none	No
Subnetting concept permitted/used	Yes	Yes	Yes	No
Completion oriented or emphasis	Not strong	Not strong to no	Strong	Strong
Milestones	By gimmicks	By gimmicks	Yes	No
Skeletonizing	Not usually	Difficult to impossible	Designed to permit	No
Ease of logic change	Difficult	Easy	Most difficult	Easiest
Overlapped activities/sequencing requirements	Requires gimmicks and extra activities	Easily handled	Difficult if not impossible	Difficult
Ability to follow float paths	Best	Difficult	Moderate	Difficult
Ease of presentation as diagram	Acceptable to Poor	Considered best	Poor	Poor
Likelihood to misinterpret output	Least	Some	Some	Most
Ease of updating/correcting logic	Moderate	High	Low	Low
Ease of preparation of network	Moderate	Low	Low	Low

Table 2.1 Important features of CPM, PERT, Precedence and GERT networking techniques

	Networking technique			
Features of networking methods	CPM	Precedence method	PERT	GERT
Ease of "banding" diagram by area type or responsibility for work	High	High	Moderate	Low
Ease of time-scaling diagram	Moderate	Moderate	Moderate	Low
Need of special, elaborate symbology	Some	Virtually none	Yes	Yes
Usefulness of diagram as working document at performer level	Moderate	High	Low	Low
Usefulness of diagram as working document at scheduler level	High	Low	Moderate	High
Ease of manual calculation	Highest	Low	Moderate	Lowest
Standardizing influence in terminology and presentation	Some	Practically none	Most	Most
Simulation oriented	No	No	No	Yes
Stochastic	No	No	Yes	Yes
Direction of flow in network	Unidirectional	Unidirectional	Unidirectional	Forward and backward

Table 2.1

with respect to cost, ACP compares (a) cost/progress relationships budgeted with (b) the cost/progress relationships extended for the task It utilizes data accumulated from periodic reports and from the same data base generates the following :

The relationship between cost and scheduled performance

The accounting relationships between cost and fiscal accounting requirements

The prediction of corporate cash flow needs'.

Unfortunately, the development of PERT/schedule techniques is still in its infancy. Although their applications have been identified, many companies feel locked in on their present method of control whether it be PERT, CPM or some other technique.

During the last two decades there have been numerous improvements and developments in the original network methods. These have resulted from the influence of management experience which helped to reconcile theoretical concepts with practical requirements. Advances in the use of computers have also made their contribution to this process. Present day methods, therefore, represents a highly developed, well tried and tested management aid. Ahuja (1976) has summarized important features of the various networking techniques given in table 2.1. Woodgate (1977) has given the development of network methods, and has visualised further developments in the form of a network given in figure 2.3. A good treatise on network analysis is given in standard texts such as by Battersby (1970) and Lockyer (1970).

2.3.1.3.2 Advantages and Disadvantages of Network Analysis

With the aid of network analysis techniques it is possible to define the scope of work in more detail, to assess the timing and resource requirements, to identify potential problem areas so that

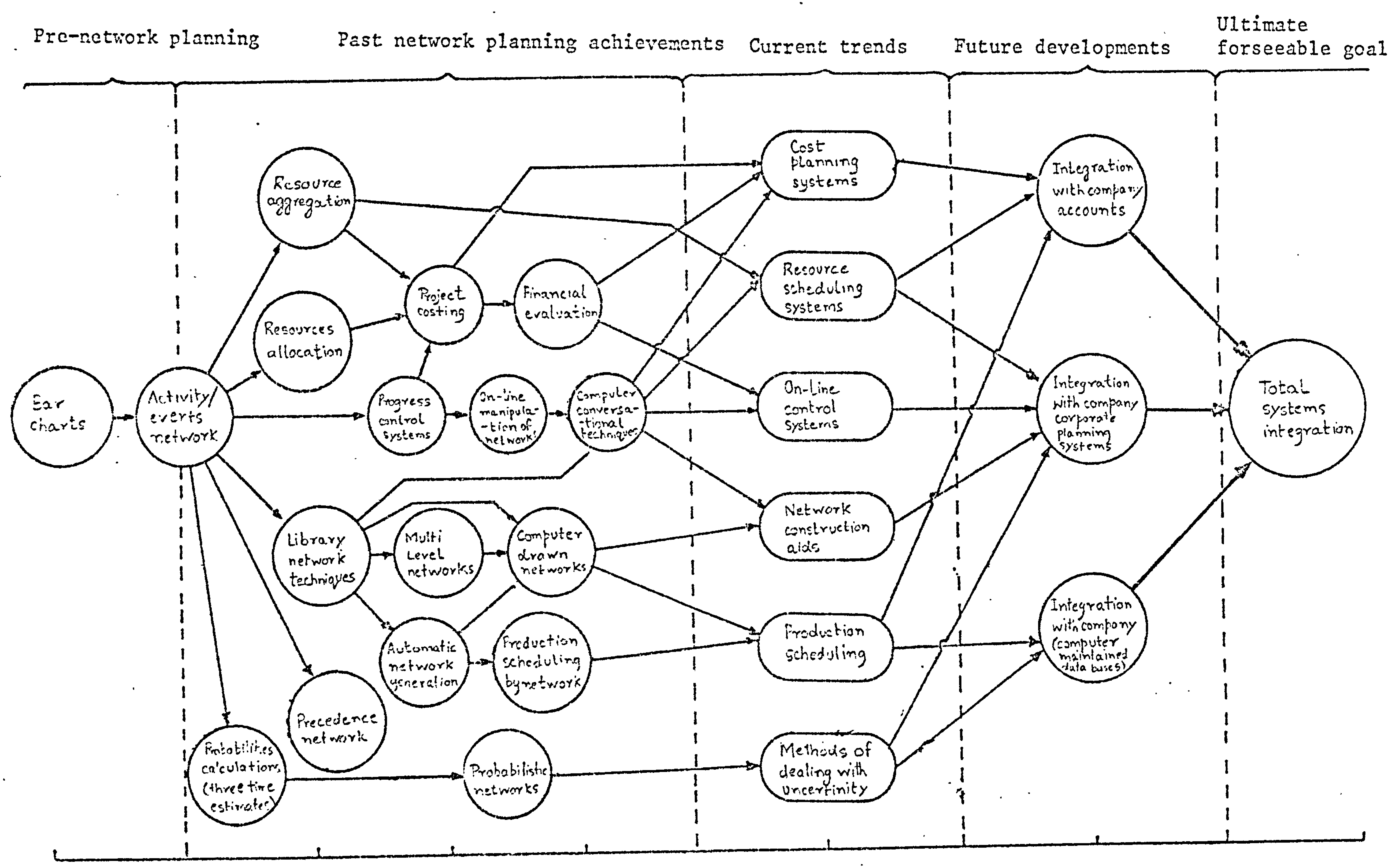


Figure 2.3 Evolution, trends and developments in network planning

action can be taken in advance of trouble, to monitor progress and reassess as situations change, as a means for management to study different courses of action, to provide a channel for communication, and for cash flow and risk assessments.

According to Woodgate (1977) the planning network, with its associated analyses, offers an integrated management planning and control system which is particularly suited to complex projects and situations with planning uncertainty. The combined diagrammatic and analytical approach to the problems of planning and control eliminates ambiguity and reduces misunderstanding between working groups. It assists all levels of project management to :

1. Define the work to be carried out.
2. Produce better work schedules based on knowledge of resources required and resources available.
3. Decide the best ways of applying resources to achieve project objectives and confirm with operative policies.
4. Establish budgets for performing the work.
5. Monitor progress and detect those points where delays would jeopardise the project objectives, in time to permit corrective action to be applied.
6. Control project costs by measuring cost progress and predicting final project costs.

Burman (1972) has summarised the advantages and disadvantages of network analysis as follows :

Advantages

(a) It separates the planning of the sequence of jobs from the scheduling of times for the jobs, thus overcoming the simultaneous, and therefore less effective, planning and scheduling of the normal bar chart methods.

(b) It shows the interdependencies between jobs (again not possible with a bar chart), and enables people to see not only the overall plan, but the ways in which their own activities depend upon, or influence those of others.

(c) By setting out the complete plan for examination by everyone involved in the project, it makes easier the task of assessing its soundness, and that of preventing unrealistic or superficial planning.

(d) It enables resource and time restraints to be included in the plan before its evaluation.

(e) By splitting up the project into smaller activities it assists in the estimation of their durations, hence leading to more accurate target dates.

(f) It allows the examination of the effects of alternative methods or of individual job estimates on the project as a whole at the outset, before any particular plan is implemented.

(g) It enables stricter controls to be applied, since any deviation from schedule is quickly noticed.

(h) It allows the total requirements of men, materials, money, machinery and space resources to be readily calculated. It indicates where the delaying or slowing down of non-critical jobs - those not immediately affecting the duration of the project - may be used to make the best allowance for any limitations in available resources.

(i) Because the network is simply a statement of logic and policy, which remains constant whether the activities take a longer or shorter time than estimated, it does not get out of date like a bar chart.

(j) It allows modifications of policy to be built in easily, and the impact of these modifications to be assessed quickly.

(k) Its identification of the critical path has two immediate advantages :

(i) if the completion date has to be advanced, attention can be concentrated on speeding up the relatively few 'critical' jobs;

(ii) money is not wasted on speeding up 'non-critical' jobs.

(l) It allows schedules to be based on considerations of costs so as to complete projects in a given time at minimum expense.

(m) It provides a more accurate and effective basis for the preparation of bar charts, resulting in better control of projects.

Disadvantages of network analysis

The only real disadvantage of network analysis as a planning tool is that it is a tedious and exacting task if attempted manually. Depending upon just what project manager wants as 'output' the number of activities that can be handled without a computer varies, but it is never very high.

2.3.2 Planning Process

To complete a project successfully, management must utilize the effective planning techniques as described in the last section. The successful accomplishment of a project requires a plan which defines all of the effort to be expended, assigns responsibility to a specially identified organizational element, and establishes schedules and budgets for the accomplishment of the work.

The first major step in the planning process is the development of the Work Breakdown Structure (WBS). The Work Breakdown Structure is the single most important element because it provides a common framework from which according to Kerzner (1979) :

a) The total program can be described as a summation of subdivided elements.

b) Planning can be performed.

c) Costs and budgets can be established.

d) Time, cost and performance can be tracked.

e) Objectives can be linked to company resources in a logical manner.

f) Schedules and status reporting procedures can be established.

g) Network construction and control planning can be initiated.

h) The responsibiliy assignments for each element can be established.

The Work Breakdown Structure (WBS) forms a basis for breaking the work down into smaller elements, thus increasing the chances that every major and minor activity is not overlooked. The Work Breakdown can be achieved in several ways. Gehriger (1972) has given an example of breaking down a project according to various criteria given in Table 2.2.

The basic element of a WBS is called a Work Package (WP). Each Work Package has a unique identification (title and number), a clear definition of what it contains, a defined start and finish date, a cost figure and a responsible organisational unit. Work Breakdown Structure provides the basis for :

a) The responsibility

b) Network scheduling

c) Costing

d) Risk Analysis

e) Organisational structure

f) Objective coordination and

g) Control

THE WORK BREAKDOWN STRUCTURE

BREAKDOWN CRITERIA	EXAMPLES
Project (Programme) Phases	Conceptual design, feasibility study, research and development (R&D), hardware design, preconstruction R&D, construction and installation, testing and commissioning, (operations).
Technical Structure	Systems, subsystems, units, assemblies, subassemblies, parts, raw materials
Organizational Structure	Partners, responsible departments, contractors, subcontractors, suppliers
Geographical Areas	Continents, countries, states, regions, counties, towns, districts, etc.
Geometrical Areas	Sectors, quadrants, sections, east wing-second floor, lower tunnel, gallery Q, etc.
Type of Work	Surveying, earth-moving, masonry, plumbing, carpentry, electrical installation
Cost Classes/Type of Expense	Labour, materials, purchased equipment, rental, travel, etc.
Appropriation of Funds	R&D money, construction money, equipment money, capital improvement money, operations and maintenance money, etc.

Table 2.2 Breakdown of projects according to various criteria

After the establishment of the basic factors relating to the project, the next step is to prepare the plans of work to be carried out - the programmes and the budget. Depending on a suitable work Breakdown Structure, detailed planning and estimation of resources and costs can be made against each of these. These then may be used to compare with the actual costs and performance for control purposes, so that remedial actions may be taken without delay, when and where necessary.

The planning process thus consists of preparing suitable programmes and specifying the resources needed; of identifying key events, decision points and interfaces in the programme.

2.3.3 Probabilistic Planning

The techniques used at present in project planning assume, generally, deterministic input data. More sophisticated procedures for handling risk and uncertainty are bound to yield substantial improvement in the realization of these techniques.

Results of a recent survey conducted by the Association of Project Managers (Internet, U.K.) on the use of modern management techniques reveals that none of the sampled organisations uses PERT or any other technique to take account of Risk and Uncertainty.

There is a dearth of literature on Probabilistic Planning techniques. Usually PERT is regarded as the Probabilistic Planning technique. However, the author couldn't find a significant number of references related to Probabilistic aspects of planning except the use of PERT. Lazar (1978) has reported some approaches which take into account the uncertainty in construction process and represents an attempt to narrow the gap between planning and reality.

Gabriel (1974) in his paper on Risk in Contract and Project Planning has provided some basic principles in this regard.

(1) Establish planning systems in the business as a sound basis on which to develop risk techniques.
Such systems should cover all activities in the business, and should be developed from the top-down, i.e. start with the high-risk area and work down to detail, using discrete levels of activity. Such levels of activity may correspond with the time scale of decision in each area.

(2) Apply probability assessments to data at source i.e. such assessments should always be made by the interested parties concerned or responsible for the plans and their achievement.

(3) Implement the system in parallel with existing ones and encourage a constant dialogue with management in the course of development.

(4) Prove and test the system on a significant business activity. It would not be taken seriously if applied to an easy and insignificant low-risk area.

The key points of his paper may be summarized as follows :

(a) Company planning as a fully integrated concept operating at discrete levels; these correspond to those of inherent risk, differing only in level of detail.

(b) Apply risk factors to planning information, then apply management effort in high-risk areas, with the object of reducing the risk of deviation from programme, rather than in remedial action after the fact.

(c) Apply resources at the early planning stage to high-risk areas - movement of resources is seldom practicable in the short term in an operating organization.

(d) Consider time and cost together and differentiate between cost control and management control.

2.3.4 Summary and Conclusions of the Section

In this section several important methods and concepts for the planning of operations and resources of an engineering and construction project are introduced and critically reviewed. The ideas discussed here are another major part of the overall system for the management of projects.

Limitations, advantages and disadvantages of three widely used techniques for planning and scheduling namely bar charts, progres curves, and network analysis are discussed. Because of its generality and power as an analytical tool, network analysis is examined in some depth. Various types of networks, their variations, important features and developments are reported.

Planning process, importance of establishing a suitable work break-down structure and probabilistic aspects of planning are considered and discussed.

2.4 Project Control

During the last two decades, planning and control aspects of project management have grown considerably in importance and became extremely sophisticated. The project-management community has recognised this as a separate discipline called 'Project Control'. In Gehriger's (1972) view project control can be considered as the totality of all organised processes and actions aimed at increasing the probability of the successful achievement of a project objective, in particular regarding cost and schedule. In detail, this involves the development and coordination of plans, schedules and budgets for a project; the obtaining of the pertinent approvals from the participating and responsible managers; the checking, preparing and monitoring of actual or forecast expenditures, progress and trends against established plans and figures. The determination of deviations and trends. The proposing, initiating and taking of corrective action as a result of the conclusions drawn from project analyses, trends and other findings. A significant aspect of project control is the continuous ensuring that the project is proceeding in accordance with a predetermined plan. The essential elements of project control are the project planning by network techniques (discussed in the last section) and the budgetting and cost control on the basis of work-package cost plans. There are other aspects, such as the control of modifications and changes in plan. The project plans, or network, strongly interact with the budgetary and cost information through a common denominator called the 'work breakdown structure'. Each of these elements, network analysis, work-package cost control, work breakdown structures, and modifications control, can themselves be considered as specialized subjects.

In this section some of these and related aspects for the establishment of an effective control system as reported in the current literature are critically reviewed.

2.4.1 Project Control Techniques

According to Hackney (1965) the techniques for control of projects naturally group themselves into those related to :

Capital cost - estimating and controlling the money invested

Time - planning, scheduling and monitoring for smooth progress toward early completion

Value - predetermining and controlling income as related to investment, operating costs, and risks.

These techniques are made effective by :

Procedures - establishing the mechanics of estimating and controlling for each of the advancing project stages.

Organisation - marshalling corporate and outside resources for effective project execution.

The three groups of project control techniques - capital cost, time and value - with their associated procedures, are interrelated.

Project control techniques include methods of assisting the planning and monitoring of performance, in terms of time-scale and cost, as well as methods of allocating resources, such as men, materials and machinery, in such a way as to achieve an acceptable utilization of the resources which are available. All of the techniques described in the last section for planning (Bar Chart, S-curve and Network Analysis) are also used for the control of a project.

Planning and control techniques facilitate :

a) Derivation of project objectives

b) Delineation of required activities (work)

c) Coordination and communication between organizational units

d) Determination of type, amount and timing of necessary resources

e) Recognition of high risk elements and assessment of uncertainties

f) Suggestions of alternative courses of action

g) Realization of effect of resource level changes on schedule and output performance

h) Measurement and reporting of genuine progress

i) Identification of potential problems

j) Basis for problem solving, decision making, and corrective action

k) Assurance of coupling between planning and control.

2.4.2 Project Control Process

The development and implementation of a comprehensive project control system are essential if the full potential of a project management programme is to be realized. The control must be based upon realistic goals developed during the planning phase. According to Barrie and Paulson (1978) a comprehensive project control system will include :

An updated and current CPM network

A design and procurement schedule showing actual progress compared with that scheduled

CPM summary schedule showing actual contract progress compared with scheduled progress for each contract

Cost report comparing forecast-at-completion costs, including committed and estimated contract costs to complete, compared with budget estimates

Value-engineering summary showing results of program to date

Weekly progress reports listing significant progress, lack of progress, current problems, proposed solutions, and other pertinent information.

Monthly progress reports summarizing pertinent information developed from the above control information

Special studies developing recommended solutions or alternate solutions to current or anticipated problems.

Control is the major managerial function and is concerned with such tasks as setting objectives, formulating policies, drawing up plans, deciding amongst alternate courses of action, and monitoring performance in order to achieve objectives. According to Wilson (1975)

"Control process involves :

1. Establishing objectives
2. Specifying way in which objectives may be achieved
3. Determining measures of performance
4. Evaluating the alternative plans and selecting the 'best'
5. Putting the selected plan into effect
6. Monitoring performance
7. Modifying performance if actual performance is deviating from desired performance (i.e. by updating plans, availability of resources)
8. Evaluating the success with which objectives have been achieved."

Kerzner has defined <u>controlling</u> as a three step process of

a) <u>Measuring</u> : determining through formal and informal reports the degree to which progress toward objectives is being made.

b) <u>Evaluating</u> : determining the cause of, and possible ways to act upon, significant deviations from planned performance

c) <u>Correcting</u> : taking control action to correct an unfavourable trend or to take advantage of an unusually favourable trend.

According to Barrie and Paulson (1978) key components of the feedback control process include : means for measuring and controlling progress; methods for information processing; requirements for effective reporting; and guidelines for taking corrective action to keep a project on target.

The most challenging part of project management is : planning and control to bring the project to completion on schedule, within budget, and in accordance with the owner's functional objectives. For this it is necessary to have full understanding of the planning and control process and all the practical tools that can be used for this purpose.

Both the client and contractor are interested mainly in the three vital control parameters :

(i) time

(ii) cost

(iii) Performance

All schedules and charts should consider these three parameters and their relationship to resources.

Effective management of a project requires that a well-organized cost and control system be designed, developed and implemented. According to Archibald (1976) the requirements for an effective control system (for both cost and schedule/performance) should include :

a) Thorough planning of the work to be performed to complete the project.
b) Good estimating of time, labour and costs.
c) Clear communication of scope of required tasks.
d) Disciplined budget and authorization of expenditures.
e) Timely accounting of physical progress and cost expenditures.
f) Periodic restimation of time and cost to complete remaining work.
g) Frequent, periodic comparison of actual progress and expenditures to schedules and budgets, both at the time of comparison and at project completion.

Management must compare the time, cost and performance of the project to the budgeted time, cost and performance not independently, but in an integrated manner.

An effective control system monitors schedule and performance as well as costs by setting budgets, measuring expenditures against budgets and identifying variances, and taking corrective action when necessary.

Work Breakdown Structure is an element which acts as the source from which all costs and controls must emanate. The Work Breakdown Structure therefore serves as the tool from which performance can be subdivided into objectives. As work progresses, the WBS provides the framework from which costs, time and schedule/performance can be compared against the budget for each level of the WBS.

According to British Standards Institution (1978) the elements of an effective project control system comprise :

(i) a well defined and structured plan, including defined responsibilities.

(ii) an adequate information feed-back system to keep in touch with progress.

(iii) an efficient decision-making procedure to keep the project going in the right direction.

(iv) good communication systems (verbal or documented-reports)

The Planning and Control system must be able to satisfy management's needs and requirements and must, therefore, provide information which

a) Gives a picture of true progress
b) Will relate cost and schedule performance
c) Identifies potential problems as to their resources
d) Provides information to project managers with a practical level of summarization.

The planning and control system, in addition to being a tool by which objectives can be defined, exists as a tool to develop planning, measure progress and control change. As a tool for planning, the system must be able to be used to

a) Plan and schedule work

b) Identify those indicators which will be used for measurement

c) Establish direct labour budgets

d) Establish overhead budgets

c) Identify management reserve.

As a tool for measuring progress and controlling change, the system must be able to

a) Measure resources consumed

b) Measure status and accomplishments

c) Compare measurements to projections and standards

d) Provide the basis for diagnosis and replanning.

Planning and control techniques and methods as applied to construction and engineering projects have been well defined by Peart (1971), Lock (1977), Woodgate (1977), Barrie and Paulson (1978), Clough and Sears (1979), Snowdon (1977), Kavanagh et al (1978), Pilcher (1976), Kerzner (1979), Ahuja (1973, 1976), Hollander (1973), Seeney (1974), Burman (1972), and British Standard Institutions (1978). Writings on cost control include Vergara and Boyer (1974), Ahuja (1976), Pilcher (1973), American Association of Cost Engineers (1972), Popescu (1976), Boyer (1976), Clark & Lorenzoni (1978), Staffurth (1980) and Kharbanda (1980).

In addition to these references a collection of a number of papers on the subject can be found in the Proceedings of the CIB W/65 Symposium on Organization and Management of Construction (1976 & 1978), Proceedings of the Project Management Institute (1974 & 1976), Proceedings of one day conference on Advanced Construction Estimating and Cost Control methods, U.S.A., 1976, and Proceedings of CIB Symposium on Assessing the economics of buildings, 1974, Ireland. These references are a recent sample on the subject.

2.4.3 Project Cost Control

Cost control is a process that should be carried out throughout the life of a project, from the inception of an idea in the client's mind to the final completion of the project and the final payment to the contractor who has constructed the work at the site.

Cost control aims at ensuring that resources are used to the best advantage.

2.4.3.1 Need for cost control

1. Rising prices, restrictions on the use of capital and high interest rates all make effective cost control that more important.
2. Greater urgency for the completion of projects.
3. Projects are becoming more complicated and the estimates of probable costs becomes more difficult.
4. Organisations are becoming larger, more complex and are adopting more sophisticated techniques for the forecasting and control of expenditure.

Project cost control is a vital part of project management. Without effective cost control there cannot be effective management (Kharbanda et al, 1980).

Realizing the need for cost control Clark & Lorenzoni (1978) reported : In recent years inflation rates and runaway costs have intensified the need for cost control in the engineering and construction industries. Due to this need, new cost estimating and control techniques have evolved and are being employed today by leading engineers, construction contractors, and plant owners. The U.S. government is now requiring that its engineers and construction contractors employ modern, sophisticated cost control procedures, and universities and technical schools are recognizing the need to introduce students to the rapidly growing field of cost engineering.

Professor Allen, D. H. (1980) in his foreward for a recent book on cost control in Action by Kharbanda et al (1980) reported

"The literature on project cost control is growing rapidly and gives the impression that the subject is one of considerable complexity and sophistication, involving extensive computerisation and data processing, but not much else ..... Project cost control is a prime example of the potential gap between theory and successful practice."

Kharbanda et al (1980) have identified some reasons for effective cost control : "Cost overruns arising from time overruns and other lapses are commonplace. The overrun can well be so serious as to prove fatal not only to the project, but also to the contractor or owner involved. Two examples will suffice. A major British contractor in the petrochemical field, faced with a substantial cost overrun on a petroleum refinery project on his home ground has a severe balance sheet problem, which resulted in a major reorganisation of the Company. In another case, with a much larger project for LNG (liquid natural gas) a major American contractor was actually 'wiped out', and that after several decades of profitable construction projects around the world. The crash of giants such as Lockheed and Rolls-Royce in 1971 can be traced quite simply to a poor cost estimate on a single project and even poorer, or perhaps more properly, not cost control. This resulted in a fantastic overrun of 300 to 400 per cent ! So cost control is undoubtedly a subject full of potential, and of real significance to all who propose to own, design or build process plants.

The cost of the projects referred to above were in the multi-million pound range, so their failure had wide publicity, but size has nothing to do with it. Small plants can go just as wildly astray as the one that reaches the headlines, and that is just as tragic for everyone involved."

According to the British Standards Institution's (1978) guide to Project Management using network techniques : "The requirements for cost control of a project, and the kind of methods used, depend on the type of project and on the controller's stance which will be either that of client or contractor. The client is concerned to have his project completed on time and to a given cost because it is a basic preamble to some long term operation. The total cost affects his operational costs thereafter in terms of size of loan and interest thereon, and project completion timing affects the amount of interest to be paid, depreciation and the point at which he can commence operation and begin earning a return on his investment. Because the client is concerned with his operational phase after the completion of the project he must also be involved in an evaluation process before the project starts. It is in this preliminary phase that the original conceptual idea of the project takes on sufficient form to test out alternative designs and proposals, one of which is finally chosen for implementation.

The contractor, on the other hand, is concerned not only with the impact of each project on the health of his company, but he seeks (i) to complete it as quickly and as economically as possible, (ii) to ensure that its overall cost is less than its overall income by a pre-determined profit margin, (iii) to finance the work with the least amount of his company's money by tight control of cash flow based on a proper match at all stages between period costs and period income.

Costs and their control should be integrated with resources and their control at all levels of project management and at all stages of the project. Cost control structures and procedures should be kept simple to minimize the response time of the control system."

2.4.3.2 Objectives of a Cost Control Program

A project cost control program has the following four objectives :

1. To focus management attention on potential cost trouble spots in time for corrective or cost-minimizing action to be taken, i.e. detect potential budget overruns before rather than after they occur.
2. To keep each project supervisor informed of the budget for his own area of responsibility and how his expenditure performance compares to that budget.
3. To create a cost-conscious atmosphere so that all persons working on a project will be cost-conscious and aware of how their activities impact on the project cost.
4. To minimize project costs by looking at all activities from a cost reduction point of view.

2.4.3.3 Elements of a Cost Control System

For any engineering/construction project, the elements of a good cost control system comprise the following five points :

1. A planned approach to the project : To realize maximum economy all activities must be carefully planned as to timing and method of execution.
2. A realistic financial yardstick : This is the control (budget) estimate.
3. Accurate and timely cost forecasts : These cover the costs to completion for all activities.
4. Comparison of forecasts to the yardstick : This is a detailed item-by-item comparison of forecasted costs with the budget.

5. Positive action to minimize forecasted budget overruns, the essential ingredient of cost control.

The technique most frequently used by the engineer to spot potential cost preoblems consists of comparing that which is actually happening with the predictions of his control budget. Isolating and correcting of a cost problem includes the following steps :

Comparison : Locates the problem

Forecast : Predicts magnitude of the problem

Analysis : Determines reason for the problem

Corrective action : Selects a lower cost alternative

Revised forecast : Reflects impact of the corrective action on projects costs.

In Clark & Lorenzoni's view (1978):

"If cost control is to be effective, the following ingredients must be present within the project management organization :

a) Management attitude that emphasizes cost control

b) Cost-conscious design/construction team

c) Capable cost control organization

d) Full-time cost follow-up

e) Good cost tools

f) Comprehensive written procedures that formalize the approach to cost control."

2.4.3.4 Project Cost Control Methods and Techniques

The basic concepts of cost control are not new. But cost control today is more vital, more necessary than ever before because of the sheer size and complexity of modern projects and the risks thereby involved.

Project cost control has in fact three dimensions :

Cost

Time

Quality and/or Performance

These three factors are interrelated and interconnected. They can all be expressed in monetary terms. They constitute an 'eternal triangle', illustrated in Fig. 2.4. (Snowdon 1977). Shorter completion times and improvement in quality will inevitably lead to higher cost.

Seeing that we are being pulled in three different directions, our target can be defined as : Project completion in a reasonable time, at an economic cost, with adequate quality.

Delay in completion of a project is prohibitively expensive, because of the immense sums tied up which are bringing no income. Delays can be avoided, and their effects minimised, by proper project cost control.

A research project undertaken by Miller (1973) examined 19 separate systems of cost control; none was found to be entirely satisfactory. Trimble & Walton (1974) discussing on the right choice of cost control technique reported "Attempts to control cost are often less successful than had been hoped . In addition the wrong choice of technique is often made and, even when an appropriate technique is used it is frequently misapplied." They have provided guidance on the selection of techniques and have described the salient points of a number of cost control techniques and the circumstances in which they can be effectively applied. The authors have also provided illustrations from their experience of civil, mechanical, electrical engineering and building projects.

Bromilow & Davies (1978) have presented a method developed at CSIRO (Australia) for financial planning and control of large programmes ofpublic works. It is known as FINPLAN and has been implemented in the Department of Public Works Western Australia.

Key trend method of project control

Lucas (1976) has presented a method known as key trend method of project control. As claimed by the author the key trend method is an accurate and reliable way of monitoring progress on building projects. Where work is proceeding in many different areas at the same time, the method is able to identify progress trends in any trade, group of trades, or in any section. Extrapolation of these trends gives management a clear indication of whether or not the project is likely to be completed on time, and identifies those trades or sections which are likely to jeopardise the completion date. The essentials of the method are as follows :

The total amount of work in a trade or section is assessed before work begins. At regular intervals the amount of this work remaining is assessed at a progress check, and recorded on a graph of time against the measure of progress. Thus the points on the graph at each successive progress check indicate actual progress at that time; the slope of the line joining the points indicates the rate of progress as shown in figure 2.5.

How fast do we need to go to complete to time ? - is indicated by a straight line between the point indicating present actual progress and the finishing date. How far should we have got according to plan ? - is indicated by the point on the line between the start date and the finishing date corresponding to the time of the progress check (Diagrams 1 and 2).

There is no need to assume that work must be programmed to complete at a constant rate. Maximum and minimum rates of progress can be

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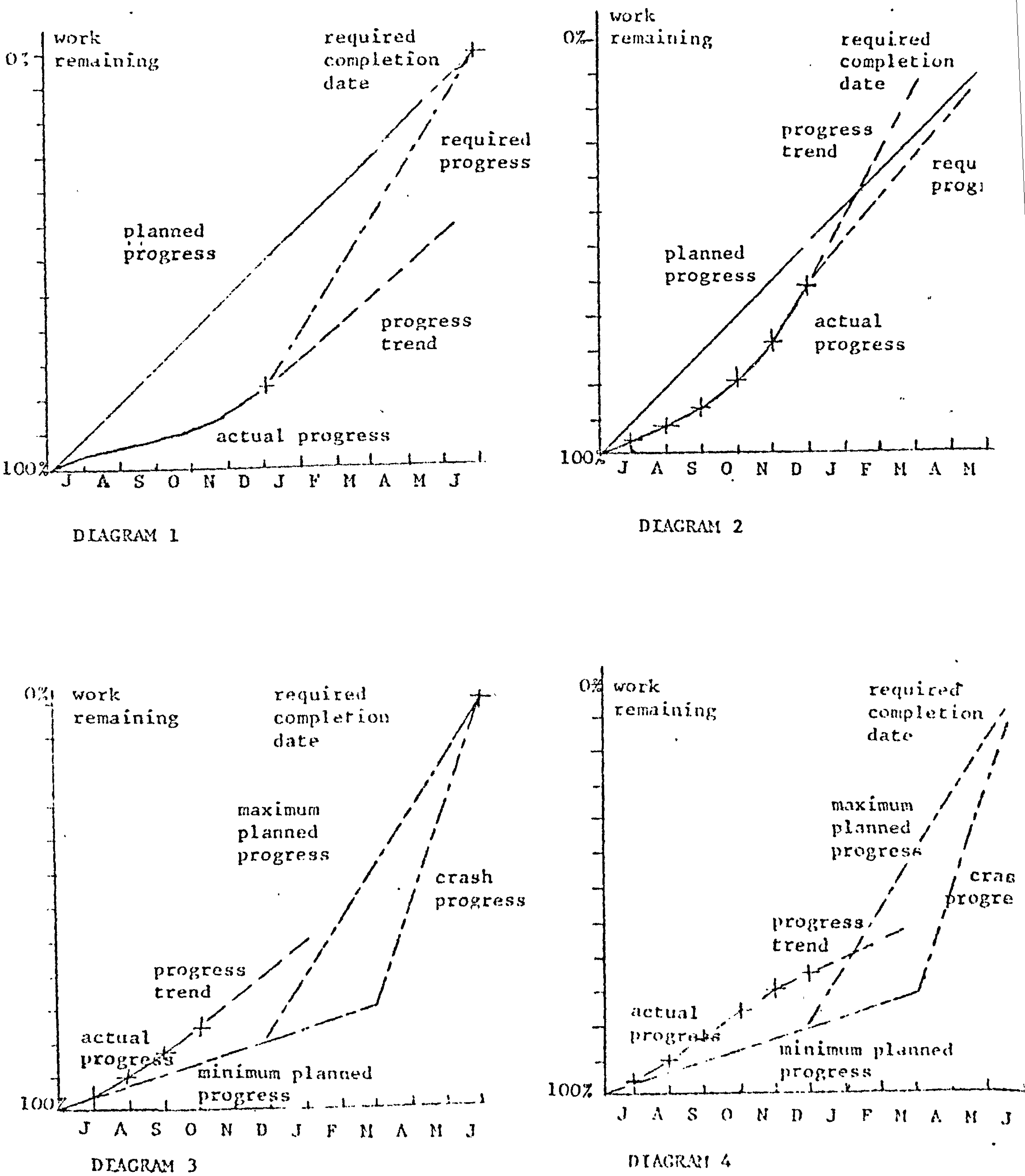


Fig. 2.5 Progress graphs for key trend method of project control

accepted, and even a crash rate of progress can be indicated on the graph (diagrams 3 and 4).

The value of this method presentation is that it enables a busy manager to judge immediately whether or not the rate of progress so far achieved on a section is, if maintained, adequate to complete the work to time. The graphical presentation above can be applied with any method of measuring work content. But the 'key trend method' is particularly powerful when used in conjunction with computer-based CPM techniques.

By concentrating on trends, on rates of progress, the method draws attention to the project control, that of completing work within a specified time. It is rate of progress that the manager needs to know in order to take effective early action.

Excess cost avoidance

Network techniques are powerful aids in dealing with complexity, but because they presuppose predictable paths and events, they are not well suited to deal with uncertainty and the 'design-manufacture-test' cycle so often found in development projects. A technique known as Excess Cost Avoidance (ECA) was proposed by Andrews (1971).

ECA explores what happens to the programme when every assumption is found to be invalid, every deduction wrong and every planned event frustrated or late. In most cases special knowledge of an activity is needed before the most serious consequence of any untoward event can be defined. This knowledge is built up systemmatically as each solution to a design problem is prepared. These analyses are collected and organised during the preparation of the planning network, on which the maximum probable estimate is based. The consequences found to be most serious form the maximum probable estimate.

It might seem that to carry out a full ECA analysis of every opportunity for misfortune would entail an inordinate amount of work. Fortunately, experience suggests that these events may have a Pareto distribution with a few of the potential occurrences accounting for most of the risk. The most convenient filter appears to be the duration of the delay that will be caused by the possible untoward event. If a delay is less than a given threshold, no further analysis is warranted. Column headings for ECA analysis are given in Table 2.3.

Having quantified the maximum probable cost if things go wrong, it remains to consider what steps may be taken to avoid such excess cost. The most attractive way is to re-arrange the programme so that all major uncertainties are resolved before any major commitment is made. Alternatively, one can limit the number of pure innovations in a major programme to one or perhaps two areas of the project. The third way is to carry out early additional experiment in an effort to reduce development cost uncertainty. Finally, some insurance actions are possible, to mitigate the consequences of the untoward event should it occur. For example, additional long lead material may be ordered - a spare may be provided in a pre-production batch - or even duplicate test rigs may be arranged.

All these solutions will involve some extra cost over and above the minimum possible estimate, but the funding authority could regard this additional cost as an insurance premium to reduce the risk of having to face much higher costs if no action is taken until the untoward event actually happens.

Column headings for ECA analysis

Analysis number and date

Project number and description

Drawing number, issue, date

Component

- Assumption or event investigated
- Possible failure
  - Description
  - Network affected
  - Path (event) number
- Consequences of failure
  - Additional work
  - Estimated delay to programme
  - Estimated cost of consequences
- Prevention or amelioration
  - Avoidable consequences
  - Means of avoidance
  - Cost of avoidance
- Unavoidable consequences
  - Cost of unavoidable consequences

Total cost element of distribution

Table 2.3

Column headings for Excess Cost Avoidance (ECA) Method

2.5 Towards an Integrated Planning and Control System

The total integration of all planning and associated systems into a single unified information processing activity is envisaged by Woodgate (1977) as the ultimate goal of the network planning, as shown in Figure 2.3.

Because of the increase in size, technical complexity, increased expenditure and longer time spans of today's projects and advances in computer technology and computer programming techniques, the current trend is for the development of interactive and integrated planning and control systems. Various computer packages, mentioned in the next section, developed for this purpose, show the progress in this direction.

Ahuja (1976), identifying the reasons and difficulties for the development of an integrated planning and control system reported :

"The main reason for the lack of a comprehensive computer-aided project management system has been the fact that no two projects are alike. Because they differ greatly in size, location, cost, and constraints, each project requires a different method of operations than previous projects. Any uniform system that could be applied to such a broad range of job conditions would be so general as to be impractical in most cases and would still be insufficient to handly many situations.

Another difficulty in developing such a system is that construction organizations differ. To be useful,a system must be compatible with the methods presently in use in a particular company. Considering the differences in size, degrees of specialization, and facilities of construction companies, it can be seen that providing a single, uniform computer system capable of fulfilling the needs of each would be an almost impossible task.

Finally such a system would have to be capable of being integrated with present management functions within the various departments of an organization. Again the task would prove unfeasible under present conditions.

It is obvious that in order to provide an integrated computer system for a construction organization it will be necessary to study in detail the present management setup and determine the needs of the company. If it is found that a need exists, the various alternatives may be examined to find the best method of performing computer processing for the particular organization."

Paulson (1976) has described basic concepts and principles necessary for the establishment of an integrated project planning and control system. After qualitatively assessing the need for improved methods for planning and control, and establishing objectives of a planning and control system, he explains the overall process with a schematic model. The flow chart in fig 2.6 models the operations, flow of information, and decision making processes characteristic of his feedback control system, appropriate for a medium to large engineering-construction project. Then he has examined the following key components of the feedback control process in greater detail :

(1) Means for measuring and controlling progress (status and progress).

(2) Methods for information processing.

(3) Requirements for effective reporting

(4) Guidelines for taking corrective action to keep a project on target.

Ahuja (1976) has suggested an integrated computer system model, using standard programs available through various sources of supply (given in Appendix B). However new programs can be designed by, and for, a specific function organization. He has divided data processing applications for construction companies into two groups. The first is processing of general accounting data such as payroll accounting, Flow chart of project control system

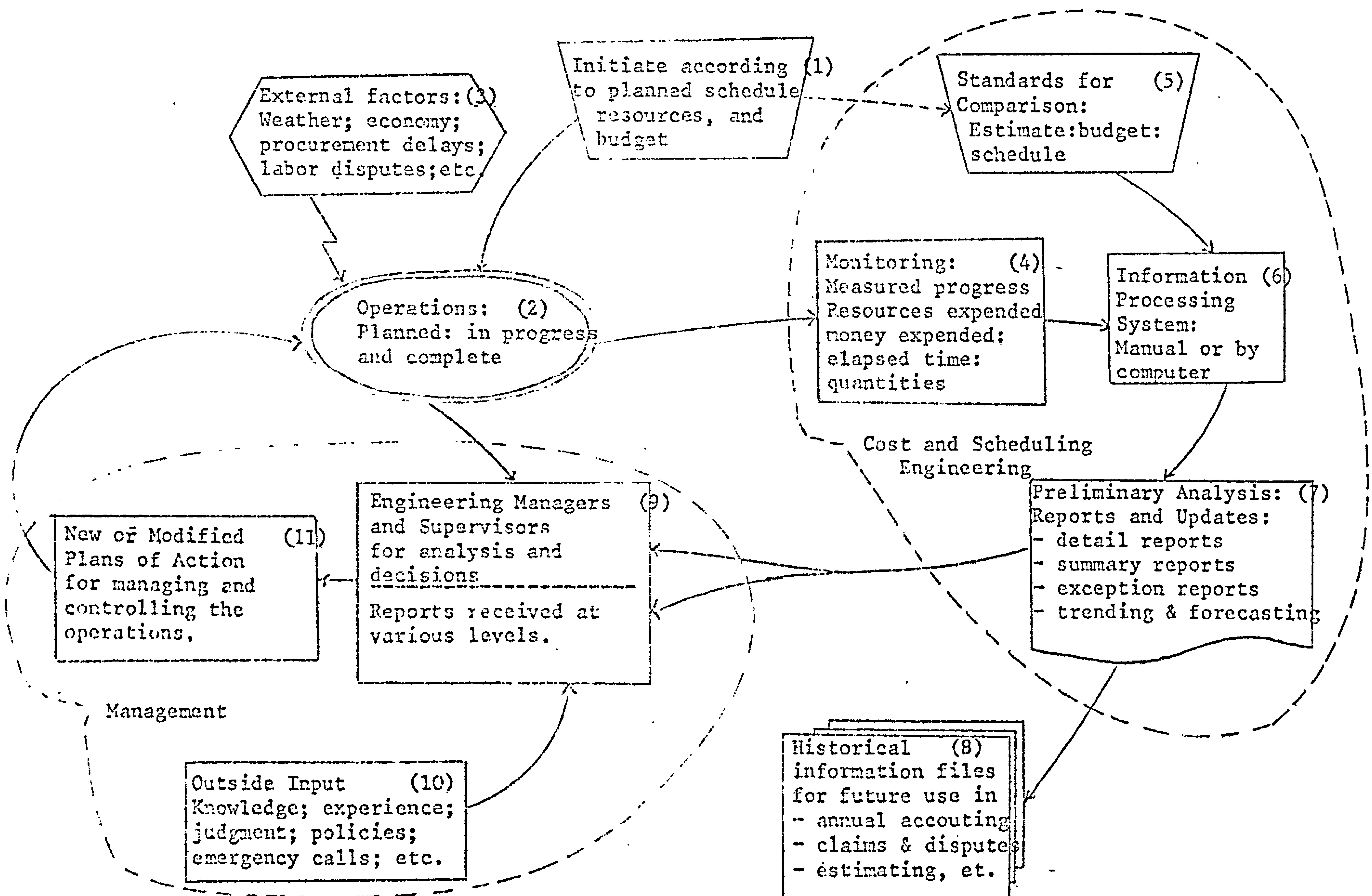


Fig 2.6 Flow chart of project control system

accounts payable, and accounts receivable. Other applications that may be included in this group are inventory control systems, in-house equipment accounting and replacement systems, and data storage and retrieval systems (i.e. data files relating to previous project costs to be used for future reference).

The second group of computer applications could be called project-oriented procedures. These are programs written to perform calculations related to the planning and control of a particular project. Programs that perform such operations as network scheduling, resource allocation, estimating, cost control, and so on, are included in this group. A complete computer processing system must incorporate both of these subsystems.

An "integrated" computer system would reduce the data from the individual procedures within the system to one common level. The system would effectively relate these procedures by means of the information passed from one to the other; however the individual programs would retain their present configurations, thus preserving the modular aspect of the data processing system. Such a design permits a step-by-step development of an overall scheme of management control. The modular concept also offers the flexibility that is so important in the highly diverse construction industry and permits the user to tailor a system best suited to his particular needs.

The system is represented in figure 2.7 by an information flow diagram showing the logical position of each program within the total management setup of the company and showing the flow of data between the various elements of the system.

The integration of these programs is achieved by reducing or changing the format of the information passed from one program to the other. This objective can be accomplished by writing programs designed

INTEGRATED COMPUTER SYSTEM MODEL

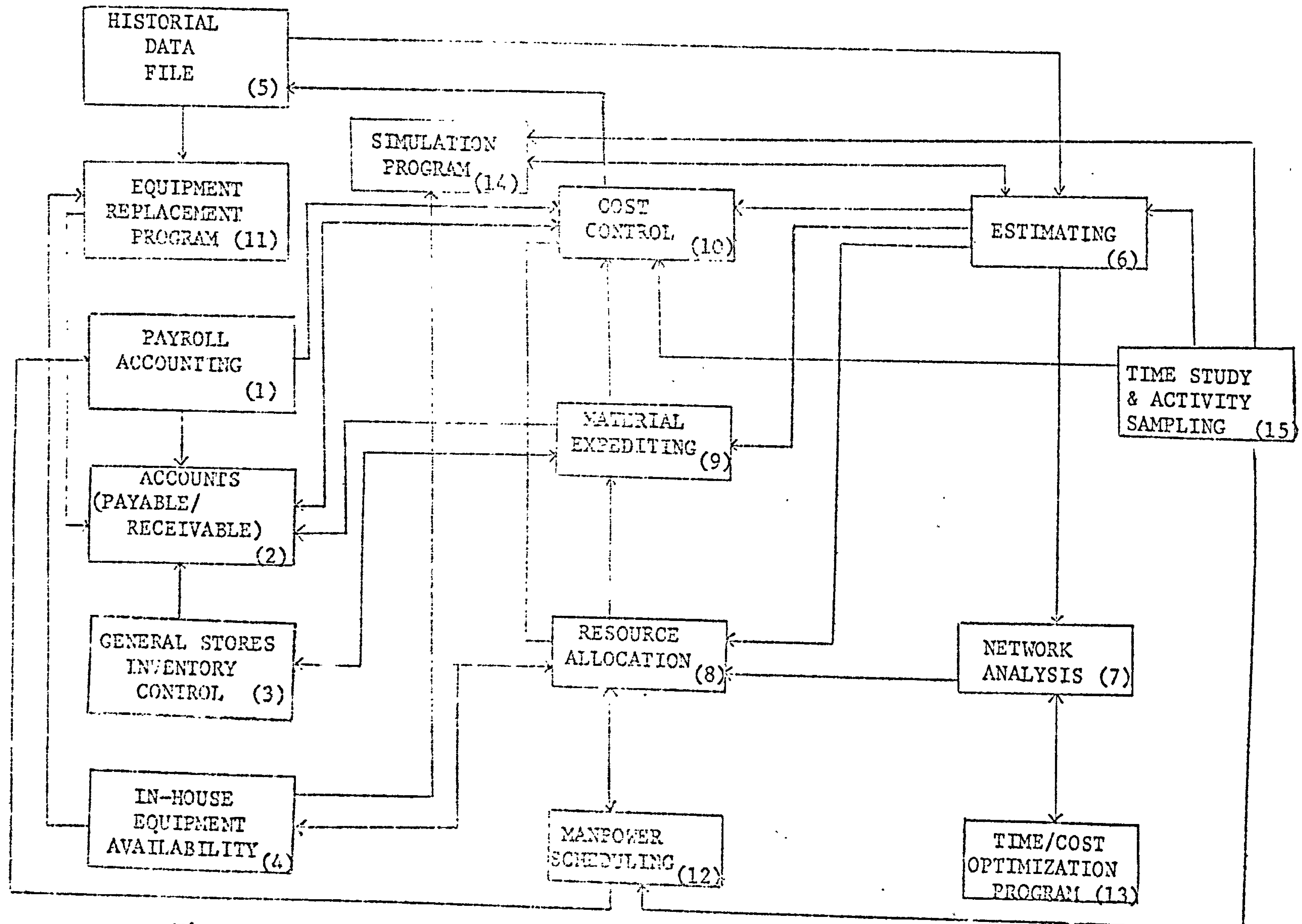


Fig 2.7 Flowchart for Integrated Computer System Model

to meet these requirements, by using program packages, or by writing interface procedures to change the format of the output from one program so that it is acceptable as input to the next. The actual transmission of data is optional as well. It may be automatic in certain parts of the system, whereas in other cases the output will be punched on cards, or stored on tape or disk, in order to allow management to study the information before it is passed on to the next procedure. Each phase must have adequate checking facilities as well.

The integrated computer system model includes programs classed as interproject and those classed as project-oriented, and also makes provisions for the many programs that are available for specific calculations in such fields as structural analysis, excavation calculations design work, and others. These programs will be classed as independent programs since they are not logically linked with the integrated system. Nevertheless such programs are extremely useful and should be incorporated into the data processing functions of the company.

Machin and Wilson (1979) have presented a conceptual framework and a practical system which can facilitate integrated corporate planning and control. They have discussed planning and control attributes, TopDown-Planning vs Control and Bottom up-Control vs Planning. Their approach is based on the concept of an 'expectation' - namely 'a requirement which one person (or group) holds of another person (or group) in connection with their jobs. From this basic concept, they have developed an integrated approach for planning and control and then systems to facilitate the use of the Expectations Approach.

The Author has developed a procedure based on two statistical models to quantify the risk associated with time/cost of a project. A typical project is divided into the following ten main activities :

1. Engineering
2. Drafting
3. Procurement
4. Construction
5. Commissioning
6. Finance
7. Insurance
8. Project Service
9. Transportation
10. Research and Development

The cost/time expenditure on each activity for a given project is analysed using Beta Distribution in which the analyst is expected to provide three estimates i.e. most pessimistic, most likely and most optimistic. The model developed provides a curve representing cumulative probability against corresponding cost/time which the activity is likely to take.

The mean, variance and standard deviation for each activity cost/time and corresponding probability of occurrence is calculated. With the application of the Central limit theorem and Normal Distribution model, the mean and variances of the activitys cost/time are combined to give a global picture of the uncertainty in a contract. Mathematical formulations of the models and computer programs developed for the purpose are reported in reference (13). The analysis was carried out in close collaboration with a major contracting organisation and provides a relatively simple method for quantifying the risk associated with time and/or cost.

2.5.1 Planning and Control Using Computers

The rapid advance of computer technology has resulted in ever increasing speeds of computing, greater availability of mass data storage facilities with fast access, and increased usage of remote computer terminals equipped with visual display units. Because of these facilities and power of computers more industries are using computers in their planning and control operations. Various computer manufacturing and management consultancy firms, universities and government agencies have developed computer programs for their own use or sale. These programs are available on almost every aspect of project management, such as Network planning techniques CPM, PERT, GERT, Precedence, estimating, Cost control, manpower scheduling, simulation etc.

An extensive list of programs available for project planning and control is provided by Ahuja (1976), with their sources, application and comments, is included in Appendix B.

2.5.2 Summary and Conclusions of the Section

In the last two sections various methods, procedures and techniques for the control of a project are discussed and critically reviewed. Guidelines are provided for an effective project control system. Due to the high inflation rates, and rising costs, particular attention is given to the cost control function of a project.

Consideration is given for the establishment of an integrated planning and control system. A guide is provided on the computer packages available for different aspects of project management.

2.6 Summary and Conclusions of the Chapter

Estimation, planning and control are three important, interdependent and essential facets of project management. The high risk nature of large capital projects demands that these operations are carried out meticulously.

In this chapter various approaches to estimating, planning and control are examined. To some extent this chapter covers most important procedures and methods necessary to accomplish a project from inception to completion in perspective of the current literature on the topics.

Planning and control requires the breaking down of a project into stages, each with a control point; the stages can be used for estimating time, allocating resources and measuring progress against the plan. Tools such as Gantt charts, S-curves and Networks can assist in the planning and control process are discussed. Control involves measurement of progress, identification of deviations, taking corrective action and producing performance statistics.

Due to the advances in computer technology and computer programming techniques, more organisations are utilizing computers in their planning and control functions. This has emphasised the need for an integrated planning and control system. This is not an easy task, reasons and difficulties in establishing such a system are discussed. Various approaches and models for this purpose reported in the current literature are reviewed. A simple probabilistic method developed by the author is presented. A guide is provided in Appendix B on the computer programs available for different aspects of project management.

The careful estimation, planning and control of a project provides the right climate for success. It is hoped that the techniques and procedures described in this chapter will help to achieve these objectives.

CHAPTER 3

ANALYSIS OF SYSTEMS GAPS AND DEFICIENCIES IN PROJECT MANAGMENT

In this chapter problems, conflicts and deficiencies in the project management systems are discussed. An anlysis of a survey on Systems Gaps is carried out. Results of the survey analysis are reported.

Project Management

3.1 Introduction

With the increase in size and complexity of projects more and more industries are adopting project and systems management philosophies in order to achieve greater efficient and effective planning and control of systems and resources.

The growth of project management has come about more through necessity than through desire. In Harold Kerzner's view (1979) project management can best be described as the planning, scheduling, direction and controlling of company resources for a relatively short-term project which has been established for the completion of specific goals and objectives. Furthermore, project management utilizes the "systems approach" to management through the use of functionally controlled personnel (vertical hierarchy) assigned to a specific project (horizontal hierarchy). Project management restructuring permits companies to :

- Accomplish tasks which were not effectively handled by the traditional structure.
- Accomplish one-time activities with minimum disruption of routine business.

Project management has matured as an outgrowth of the need to develop and produce complex and/or large projects in the shortest possible time, within anticipated cost, with required reliability and performance and to realize a profit.

Middleton (1967) conducted a survey of aerospace firms in an attempt to determine how well the companies using project management met their objectives. Middleton stated :

"In evaluating the results of the survey, it appears that a company taking the project organization approach can be reasonably certain that it will improve controls and customer (out of company) relations, but internal operations will be more complex."

J. Robert Flour (1977), Chairman, Chief Executive Officer and President of the Flour Corporation*, U.S.A. commented on the twenty years of operations in a project environment :

"The need for flexibility has become apparent since no two projects are ever alike from a project management point of view. There are always differences in technology; in the contract terms and conditions; in the schedule; in the financial approach to the project; and in a broad range of international factors, all of which require a different and flexible approach to managing each project.

We found the task force concept, with maximum authority and accountability resting with the project manager, to be the most effective means of realizing project objectives. And while basic project management principles do exist at Flour, there is no single standard project organization or project procedure yet devised that can be rigidly applied to more than one project.

Today, our company and others and their project managers are being challenged as never before to achieve what earlier would have classified as "unachievable" project objectives. Major projects often involve the resources of a large number of organizations located on different continents. The efforts of each must be directed and coordinated toward a common set of project objectives of quality performance, cost and time of completion as well as many other considerations."

As rightly said by J. Robert Flour, there is no doubt that project management and systems approach is accepting that challenge. That is why twenty years ago project management was confined to the Department of Defense contractors and construction companies in U.S.A., but now

* Flour Corporating is a large contracting company in the U.S.A.

project management has spread to virtually all industries, including defense, construction, pharmaceuticals, chemicals, banking, accounting, advertising, law, hospitals, state and government agencies and the United Nations (Kerzner).

There are numerous treatises on different aspects (39, 130, 139, 165, 166) of project management and its success in achieving better planning, control, coordination and management of resources. Despite the success of project management in achieving these goals, opponents of project management assert that the major reason why many companies avoid change-over to a project management organizational structure is either because of fear, or because of an inability to handle the resulting conflicts (Kerzner). Conflicts are a way of life in a project structure and can generally occur at any level in the organization, usually the result of conflictive objectives. The ability to handle conflicts requires an understanding of why conflicts occur, and this is considered in the next section.

3.1.1 Problems and Conflicts

As project management grew, it soon became evident that there must exist some guiding factors which form the basis for the underlying principles behind the project management approach. The first factor was the establishment of the project manager as the focal point for the integrative responsibility. The second key factor was the establishment of an integrated planning and control system which would effectively "marry" the horizontal and vertical units of the company toward better project identification and control (Kerzner).

Unfortunately, these two factors are somewhat constrained by the fact that :

- Each project is normally of a finite time duration and exists as a separate entity within the company except for administrative requirements.

- The resources must be scheduled and fitted to satisfy the needs of the project, not vice versa.

Organizational restraints have the tendency of developing into organizational conflicts.

Three major problems were identified by W. Killian (1971):

- Project Priorities and competition for talent may interrupt the stability of the organization and interfere with its long-range interests by upsetting the normal business of the functional organizations.
- Long-range planning may suffer as the company becomes more involved in meeting schedules and fulfilling the requirements of temporary projects.
- Shifting people from project to project may disrupt the training of new employees and specialists. This may hinder their growth and development within their fields of specialization.

The two other major problem areas are the authority/responsibility relationship and the conflicts at the project/functional interface and resources.Killian (1971) defined this inevitable conflict between the functional and project manager :

"The conflicts revolve about items such as project priority, manpower costs, and the assignment of functional personnel to the project manager. Each project manager will, of course, want the best functional operators assigned to his program. In addition to these problems, the accountability for profit and loss is much more difficult in a matrix organization than in a project organization. Project managers have a tendency to blame overrun on functional managers, stating that the cost of the function was excessive, whereas functional managers have a tendency to blame excessive cost on project managers with the argument that there was too many changes, more work required than defined initially and other such arguments."

Wilemon, D. L. (1972) investigating project management and its conflicts with the Appolo project reported the following views of a manager :

"The main conflict that occurs within NASA is between technical side and project side."

Wilemon, D. L. (1972) has further identified several reasons why conflicts occur :

- The greater the diversity of disciplinary expertise among the participants of a project team the greater the potential for conflict to develop among the members of the team.

- The lower the project manager's degree of authority, reward and punishment power over those individuals and organizational units supporting his project the greater the potential for conflict to develop.

- The less the specific objectives of a project (cost, schedule and technical performance) are understood by the project team members the more likely that conflict will develop.

- The greater the role played by ambiguity among the participants of a project team the more likely that conflict will develop.

- The greater the agreement on superordinate goals by project team participants, the lower the potential for detrimental conflict.

- The more the members of functional areas perceive that the implementation of a project management system will adversely usurp their traditional roles, the greater the potential for conflict.

- The lower the percent need for interdependence among organizational units supporting a project, the greater the potential for dysfunctional conflict.

- The higher the managerial level within a project or functional area, the more likely that conflicts will be based upon deep-seated parochial resentments.

By contrast, at the project or task level, the more likely cooperation will be facilitated by the task-orientation and professionalism that a project requires for completion.

3.1.2 Managing Conflicts

Temporary management situations often produce conflicts resulting from

- the differences in the organizational behaviour of individuals and
- the difference in the way that functional and project managers view the work required.

There is no one single method which will suffice for managing all conflicts in temporary management situations because :

- There exist several type of conflicts
- Each conflict can assume a different relative intensity over the life cycle of the project.

The detrimental aspects of these conflicts can be minimized if the project manager can anticipate their occurrence and understand their composition.

Thamhain and Wileman (1975) surveyed 150 project managers on conflict management. Their research tried to determine the type and magnitude of the particular type of conflict which is most common at specific life cycle stages, regardless of the particular nature of the project. Their study is devoted to the causes and management of conflict in specific project life cycle stages. Their study first investigates the mean intensity of seven potential conflict determinants frequently thought to be prime causes of conflict in project management. The seven potential sources of conflict are :

1 Project priorities

2 Administrative procedure

3 Technical opinions and performance trade-offs

4 Manpower resources

5 Cost

6 Schedules

7 Personality

A number of ideas evolved for improving conflict management effectiveness in project-oriented environments from their research. Three areas most likely to cause problems for the project manager over the entire project cycle as identified by them are

a) disagreements over schedules,

b) project priorities and

c) manpower resources.

Kerzner (1979) reported that with their discussions with project managers who have experienced problems in these areas, almost all maintain that these problems frequently originate from lack of effective pre-project planning.

One method for reducing conflicts and minimizing communications gaps is through detailed planning and involvement of all the concerned groups.

3.2 Systems Deficiencies and Gaps in Project Management: Identification and Discussion of Causes

Not enough attention is directed to these conflicts, which give rise to deficiencies and gaps in the systems. The different interests and perspective of the people involved in a project are perfectly right and proper, and unavoidable. But they do leave deficiencies and gaps which are the cause of ineffectiveness of many integrated systems. These systems need to recognise the different needs of each discipline, and users do not feel responsible for them. Fig. 3.1 (Kerzner, 1979) gives an example of how different gaps make operational islands.

Realising the need for a detailed study to analyse the causes of these deficiencies and gaps in the systems, and to propose potential remedies the Association of Project Managers (INTERNET) in the U.K. set up a working group in early 1979. A list of the members of the working group is given in Appendix C.

The objectives of the study were:

1) identification of gaps
2) problems resulting from gaps
3) analysis of causes of existence of gaps
4) propose solutions.

The systems gap working group identified and specified the main areas where the gaps exist. E. Gabriel (1979), Chairman of the working group has reported these gaps. A summary of the causes of the gaps is presented and discussed in the next section. After identifying these gaps the Internet working group prepared a questionnaire to collect data for the anaysis of causes of existence of gaps and to propose solutions. The questionnaire was sent to a number of organisations in U.K. The author has analysed the responses of the questionnaire. A summary of the analysis results is presented in Section 3.4.

The gaps studied are grouped under the following headings:

Figure 3.1 Why are systems and project management approaches necessary ?

1. Organisation
2. Project Environment
3. Procedures
4. Data Processing

The gaps are either caused or exacerbated by the approaches selected in these areas, and each title is discussed in a little more detail.

3.2.1 Organisation

The system gaps related to organisation are depersonalised accountability, loyalty conflicts, central/site communication, staff availability and training.

3.2.1.1 Project Organisation

(a) Hierarchy-related problems arise from several causes : the organisation structure may not be adapted to suit the changing requirements of the project.

(b) Responsibility may be delegated without the necessary attendant authority.

(c) Responsibilities and duties are not always defined sufficiently well in the early stages of a project leading to deficiencies and misinterpretation later, and possibly to confusion, and even rivalry, between overlapping interests.

It is suggested that control should be exercised where the responsibility lies, i.e. where the decisions are made.

3.2.1.2 Differences in loyalties to project team and to functional disciplines :

(i) Where project staff are seconded from functional department, as in a matrix organisation, there may well be differences in approach required from the two departments, due to :

(a) differing priorities, especially where a department is providing staff for several projects, and people of the calibre needed are scarce;

(b) support for a project differing from the normal company service provided by that department;

(c) staff reporting to two managers, whose aims may well be different.

(ii) As projects are of a transient nature, the attitudes of people working on these projects is substantially different from that of the more established and permanent departments.

(iii) Project management support staff and project engineers often do not have sufficient involvement in the management of their projects (especially if they are large).

3.2.1.3 <u>Differences in central and site requirements</u>

(i) Because of the geographical separation between central and site organisations, the respective staff may not have sufficient contact to provide a proper understanding of each other's problems and attitudes which usually results in lack of cooperation, professional jealousies and communication problems.

(ii) Decentralisation imposes a certain amount of autonomy in the non-central organisations, and so co-ordination between them becomes important, requiring adequate, simple communication systems with a fast turn-a-round.

(iii) The objectives of client and contractor in many ways are diametrically opposed, especially in relation to cash flow, time scales and level of details over which work has to be planned.

3.2.1.4 Problems relating to staff numbers :

(i) The balance between having too few staff so that an adequate service cannot be provided, and too many so that duplications and interference occur, is often not achieved.

(ii) The build up of staff at the beginning of any project is almost invariably slower than planned.

(iii) Often the right staff are not consulted at the early stage of design and specification.

(iv) There is often a gap between the experience and knowledge needed in modern project management and the ability of the staff available.

3.2.1.5 Training

There are gaps in effective practical training for project management, as :

(i) Insufficient training is provided to project staff on the requirements and procedures to be followed within the project environment.

(ii) With a shortage of experienced staff, formal training in the various disciplines and techniques involved in project management is more extensively needed.

(iii) "On the job" experience, which is progressive in development, must be recognised as a necessity.

3.2.2 Project Environment

The project environment is an important ingredient of a successful Project Management, and a prime objective of Project Planning.

The project is composed of two main elements;

(a) Direct responsibilities for its execution for the provision of services;

(b) parts of diverse organisations contracted to provide goods or services.

Gaps between these two elements, and within the constituent parts of each of them should be minimised to ensure effective performance.

Many factors contribute to the environment, of which the Project Teams, Specialist Functions, Consultants and Temporary Staff are considered to be important.

3.2.2.1 Project Teams

These usually exercise the following five functions :

a) General Management and Client Liaison

b) Technical and Performance Aspects

c) Site Construction Planning and Co-ordination

d) Materials and Sub-Contracts

e) Project Control and Systems

However there are gaps in the above functions which should be bridged.

3.2.2.2 Specialist Functions

The Specialist Functions are taken to include planning, cost control, accounting, personnel, administration, evaluation and audit.

Gaps between the related functions of programming, cost control, and cost accounting are common, and the Team should seek to establish a consistant work split-up and a common data base as far as practicable.

3.2.2.3 Consultancy

In view of the importance of user-driven systems, and the temporary nature of a Project, Specialist Consultants have a useful role to play in the bridging of gaps which may arise between systems and users. The absence of a permanent commitment to the project can be of advantage, permitting relatively rapid action to be taken which might otherwise founder upon intra-organisational problems and frictions. Consultants should never be part of the Project team, but identified with the areas most concerned in the particular gap or problem.

Consultants are advisable if and only if the manpower resources of the organisations are being fully utilized on other programs or if the organisations do not possess the required project skills.

3.2.2.4 Temporary Staff

Contract labour, or short engagement staff from a variety of disciplines can contribute usefully to a Project in some circumstances. Advantages are :-

(a) Short-term needs are difficult to supply from established organisations, particularly for overseas assignments.

(b) They provide a ready means of meeting the temporary peak loads which usually occur in practice.

(c) They permit an organisation to bridge gaps in manpower availability between the completion of one Project and the start of another.

There are serious disadvantages, however, as follows :-

a) Motivation difficulties arise, due to lack of commitment.

b) Training may be required, which is expensive in time and money, and moreover is lost to the organisations concerned.

c) High Specific cost.

In general, the use of short term staff should be avoided if possible.

3.2.3 Procedures

Project procedures have their major impact on the planning and Monitoring (or reporting) phases. The gaps arising are discussed under the following headings :

(i) Planning

- (a) Work break-down
- (b) Level of detail

(ii) Monitoring

- (a) Data capture
- (b) Reporting frequency
- (c) Data volumes

(iii) Information and its Uncertainty

3.2.3.1 Planning

(a) Work Break-down is the first essential of planning. Major gaps occur through the cost-time conflict. Breakdown of the work for cost purposes according to pre-defined account codes may be quite inconsistent with the way the work will be physically performed and can lead to problems for project management in reconciling cost and progress status. This gap can be substantially closed by recognising that the most effective cost control system reflects the way the work is performed, dividing the project into "work packages" consistent with the project plan. These packages are of limited duration, with identifiable start and finish dates. Costs are budgetted and monitored on a package by package basis.

The choice between work break-down by discipline or area of the project will cause major gaps if it is not consistent with the division of responsibility for technical adequacy, target dates and budget. Responsibility, work split-up and authority over areas of the work must be consistent for effective project management.

(b) Level of Detail must be appropriate to the organisation and the control procedures, gaps will arise where the work split-up is such that it is not possible to provide information at the right level of detail for each project participant. The work split-up must reflect the project management hierarchy.

3.2.3.2 Monitoring

The aim of monitoring the project is to report status in such a way that problems can be identified in good time at an appropriate level of management for effective control (or correcting) action to be taken. Gaps may arise as follows :

a) Data Capture must be set up so as to require minimum effort from project staff and so as to leave as little scope for error as possible.

Users need to understand the usefulness of the data they supply. The emphasis for cost system, as for planning systems, must be to look forward, making use of lessons learned from past performance.

b) Reporting Frequency must reflect the management time-scales of those receiving reports. Too-frequent reporting will lead to indigestion; too-infrequent will lead to ad-hoc informal systems being established to supply information not provided by the formal system. Close-out dates should be synchronised for cost-time information.

Immediate needs for particular data must be recognised by providing facilities for project staff to obtain up-to-date reports on request.

c) Data Volumes, as for reporting frequencies, must be consistent with the management levels of those using the data. Excessive data volumes will lead to excessive effort in data capture and reports which are not read. Too little volume will not provide sufficient information for effective management.

3.2.3.3 Information and its Uncertainty

Most of the techniques used are based on deterministic formulations though some use is occasionally made of "three-time estimates". This is despite the practical reality, in which invaraibly some activities are completed late, and very often the entire project runs late producing losses both for the contractor and client.

This gap between deterministic planning and the uncertain reality should be taken into account in project planning and control systems in a way that is both realistic and is an effective aid to the project manager.

3.2.4 Data Processing

With the constant refining and increasing user orientation of computerised project planning systems, there is an opportunity to narrow the gap between computer systems and Project Managers.

3.3 Analysis of Internet (U.K.) Survey on Systems Gaps

The systems gap working group after identifying and specifying the main areas where the gaps exist, prepared a questionnaire in order to collect information regarding the current practices of managing current projects. The questionnaire was distributed to a variety of organizations in the U.K. Sixteen responses were received 'till mid 1980. It is believed that these are fairly representative of the Companies using project management and defines the current level of usage of these practices in the U.K.

The questionnaire was divided into six sections covering the following areas

1. Orgnisation
2. Work breakdown
3. Data volumes
4. Data capture
5. Planning methods
6. Computing.

A copy of the questionnaire form is given in Appendix C2

The results of the survey analysis are presented in tabular form in Appendix C3

Some of the important general features of the survey under the above headings are presented in the next section.

Usually a project is carried out in two ways: either the management of the owner of the project manages and control the project or the project is completed by a contractor. In this analysis the first one is referred as client/owner and the second one as contractor. The differences in practices of management and behaviour of the client and contractors have been noted, and are presented in Appendix C4.

3.4 Results of the Survey Analysis

3.4.1 Organisation

a) Most of the projects reported on were of £5-25 (m) value, and of 1 - 3 years duration; and the management of all was located in the U.K.

b) In most of the cases the project manager was responsible to the Project Director. During the design-procurement phase, for 80% of the projects the project manager was at Home Office, but during the construction phase for 44% of the cases he was at Site.

c) In most of the projects temporary staff was employed mainly due to shortage of permanent staff and/or increased workload. The temporary staff employed was generally found to be equally competent, only in a few cases the temporary staff was found to be worse than the permanent staff.

3.4.2 Work Breakdown

a) Most of the firms use physical work packages whereas a few use cost codes as a basis for major work breakdown structures.

b) Most of the firms use over four levels in the major work breakdown.

c) Usually there is either a <u>non</u> or <u>detailed</u> link between the work breakdown structure, used for cost control and that used for progress control, a few firms have a <u>summary</u> or <u>intermediate</u> link.

d) In nearly all the projects budgets were <u>always fixed before</u> cost commitments were entered.

3.4.3 Data Volume

a) Most of the projects had 1-500 activities and 2 levels in the project plan.

b) Most of the projects had under 100 activities in the level one, 100-500 activities in level 2, a few had 1000-5000 activities in levels 3 and 4 and 500-1000 activities in the lowest level.

c) In the majority of projects, the update/review period for progress and cost monitoring was on a monthly basis.

d) In most of the projects, there were under 100 work packages for cost control, a few had 100-500 work packages as well.

e) In most of the projects, a time delay of up to 2 weeks was observed between the data cutoff and report issue for cost and progress control.

3.4.4 Data Capture

a) In the majority of the cases the information used for updating was independent of time and cost.

b) In most of the cases update information for the project network and cost was obtained by Review meeting and Progress chasing, and in some cases by computer-produced schedule or proforma return.

c) Most of the firms recorded historical progress, deployment of resources and cost information.

3.4.5 Planning Methods

a) Most of the firms used a computerised system for networks and cost control, and a few used a computerised system for procurement.

b) In most of the cases the computerised cost control and procurement system was not linked to the computerised network.

c) In the majority of the cases achievement was late with respect to planned dates and was on or over budget (1) with respect to costs.

d) No attempt was made in any of the respondent firms to recognise or take into account associated Risk and Uncertainty by PERT or any other method.

3.4.6 Computing

a) Most of the organisations use an in-house computer system with mainframe and generally input data by terminals.

b) Most of the organisations use packages for planning/networks, and in-house developed computer programs for cost control. A few use in-house developed programs for planning/networks and materials control.

c) In the majority of the organisations Data Processing support is provided by a DP department.

d) Most of the users had received formal training in the use of network/time control package.

3.5 Conclusions of the Survey Analysis

Most of the important features of the survey have already been highlighted in the previous section. In this section some of the finer points evolving from the study of the survey analysis are presented. Some general conclusions of the survey analysis are given as in 1-4. Some differences in the attitudes of the projects managed and completed by owner and by contractors clients have been noted and are given as in 5-12.

1. In the majority of cases information used for updating time and costs was obtained from independent sources. This is a very important factor and there is an obvious need to link the cost and time elements.

2. Most of the firms keep historical information for progress, resource usage and cost but there is no indication whether this information is used for improving the system or for future planning, in fact the reverse is indicated.

3. Most of the organisations use computerised network, cost control and procurement systems. But most of them do not have their procurement and cost control systems linked to the computerised network.

4. No attempt was made by any of the sampled firms to take account of Risk and Uncertainty by PERT or any other technique.

5. For most of the large projects contractors were responsible for the management and completion of the projects.

6. For most of the projects, completed by clients themselves, the project manager was at Home Office during the design-procurement and construction phases. Whereas for most of the contracted projects the project manager was at site during construction phase and for a few projects was at site during the design-procurement phase.

7. Contractors seem to be relatively efficient for cost control and the clients for the progress control.

8. No client has the time and cost information related, whereas most of the contractors have the two elements related.

9. Most of the clients obtain Project network and cost information by Review meeting and progress chasing, whereas most of the contractors obtain it by Progress chasing and proforma return.

10. No client has his computerised cost control system linked to a computerised network, whereas a few contractors do have many such linked systems.

11. The final cost of most of the projects completed by clients/owners

were over budget; whereas most of the projects completed by contractors were within budget.

12. Most of the contractors have had formal training in the use of network/time control packages whereas most of the clients have had no such training.

Note

(1) Mr Castell one of the member of the Systems Gap working has pointed out differing views of clients and contractors regarding "budgets" referred in Section 5.7 of Appendix C3. Section 5.2 of Appendix C4 and conclusion 11.

In contracting organisations there is a tendency to refer to the budget as the last agreed budget with client organisation. Conversely within clients organisations it is common to refer to the "budget" as the originally planned expenditure for the project. Thus for the same project a client organisation will state that the project is 100% overspent, whereas the contracting company will claim to be on target.

However these differing views of clients and contractors organisations on the definition of budget were neither mentioned in the questionnaire form nor in the responses. In the author's view clients and contractors have supplied this information according to their own interpretation of "budget".

3.6 General Conclusions

Project Management has evolved as a need to manage, plan and control large capital projects more effectively and efficiently. Many authors have reported the success of project management approach. But still many projects are controlled less effectively than they could be. The transient nature of a project, and the conflicts in authority/responsibility make project control more difficult and complex than the control of an on-going industrial enterprise. Information gaps develop between the areas of work and the systems, and between the different elements of the organisation involved. The gaps between the systems and the various people involved present the most serious obstacles to effective project control and management.

Consideration has been given to the questions that arise during project management, in particular the general problem of communication gaps - between different parts of the same organization and between different organizations.

The literature on the subject has been critically examined and discussed.

The discussion about these problems, summary of the Internet report on systems gaps, and analysis of a survey on current practices of modern management techniques is principally aimed at project control and project management people to help them understand the causes of the deficiencies and gaps in the systems so that they can get maximum usefulness from the systems and resources at their disposal. It has emerged from the study that gaps exist in time and cost, people and systems, doing and managing, and information and action. The key to success is in bridging these gaps and the involvement by all concerned on the project.

CHAPTER 4

PLANNING AND CONTROL OF PROJECT EXPENDITURE/ EFFORT USING AN S-CURVE MODEL

In this chapter an S-curve model for project expenditure prediction originally proposed by Keller & Singh is used for thispurpose. The model is compared with the one proposed by the Department of Health and Social Security (D.H.S.S.). Both the models are fitted to the actual expenditure data for more than 20 recent projects. The predicting accuracy of the two models is compared and a set of standard parameters for the two models is obtained.

4.1. Introduction

Project cost control is a vital part of project management. Without effective cost control there cannot be effective management. Effective and meaningful cost control must begin even before the design stage and should be maintained by proper and scientific cost estimation and data analysis. Kharbanda, O.P., et al (1980) have reported "Cost control function can save up to five per cent of project cost, and the extra cost of project control? Perhaps 0.5 per cent - certainly not more. Isn't it worth it?". If a company is to control its capital expenditure (and working capital requirements) then it is necessary to have a plan which provides the framework for future operations. The more keen the competition is within the particular industry concerned, then the more necessary becomes the use of an accurate and soundly based forecast for the future. Pilcher, R (1973) has reported that "A useful method for forecasting the cash requirements of a project, is that which makes use of an S-curve. This curve draws its name from the fact that the cumulative expenditure for a project typically takes its shape as that of a letter S, even if it is a rather flat form of that letter. Because of this it is possible, as a result of observation, to draw up a curve on an empirical basis which predicts the way in which expenditure will occur".

The S-curve for expenditure or value of work done follows the same path when expressed in percentage terms. Hardy (1970) demonstrated that, within a company, projects of the same type had similar shapes of cumulative value v. time when expressed in percentage terms.

In these days of capital scarcity, high interest rates, inflation and cash limits, the need for a reliable method of forecasting the flow of capital expenditure on projects is even more important. The forecasting of the incidence of expenditure curves is a very useful tool for management for various reasons. It may be used for:-

1. initial budget expenditure forecasting
2. the preparation of tenders
3. the control of capital investment and
4. anticipation of future commitments and in particular between expected expenditure and the total allocation of funds as is the case usually in many government projects.

Major projects in general consist of a number of sub-projects, each sub-project having a relatively well defined beginning and end. Again each sub-project will require an amount of labour and expenditure to be associated with its execution.

Usually clients make an estimate of total cost and duration of a project before inviting tenders for it. Contractors also make such estimates for the cost and duration of the project before bidding for it.

For this purpose both have to do an effective evaluation of the proposal and derive a cumulative expenditure curve based on an agreed physical programme of work, anticipated expenditure and payments. This is particularly important for the contractor, as he has to estimate the financing and servicing costs of the project. For projects of duration greater than one year, these financing costs may offset the profit of the contractor, or may increase the cost of the project to the client. For this reason "progress" or "stage" payments are usually agreed between the contractor and his client. The basis for making stage payments is usually agreed against an "incidence of expenditure" curve. Thus they both need some estimate of the likely expenditure over the course of the project. Therefore, the expenditure curve provides a basis for clients and contractors for their financial planning in general.

To smooth the discontinuities usually the cumulative costs are considered. The basic information necessary for producing future expenditure forecasts is:

total cost of the project

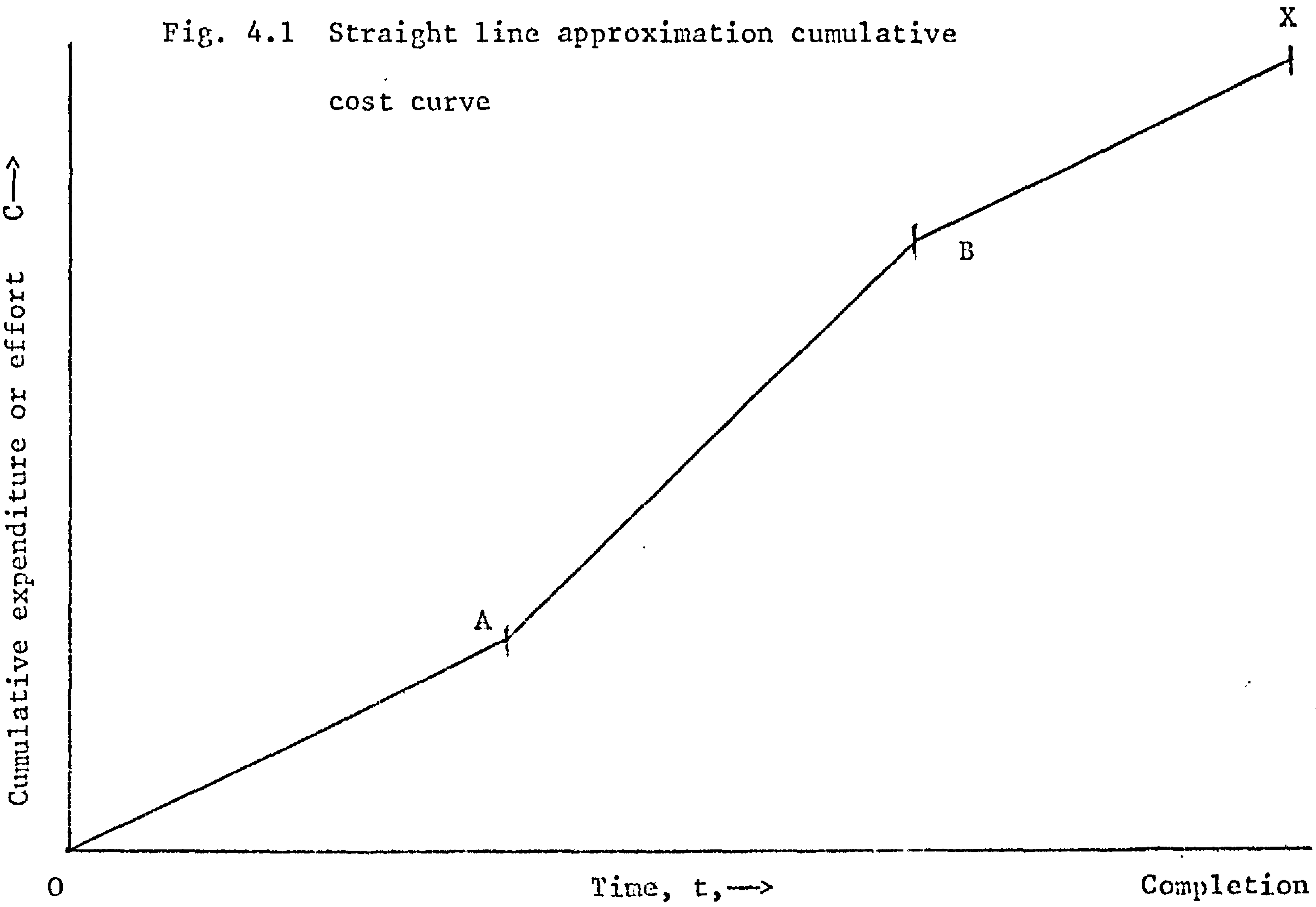
total duration of the project

the time when maximum rate of expenditure is to be utilised (ie. at the start, middle or end of the project).

nature of the project (eg. civil, mechanical, new technology etc.)

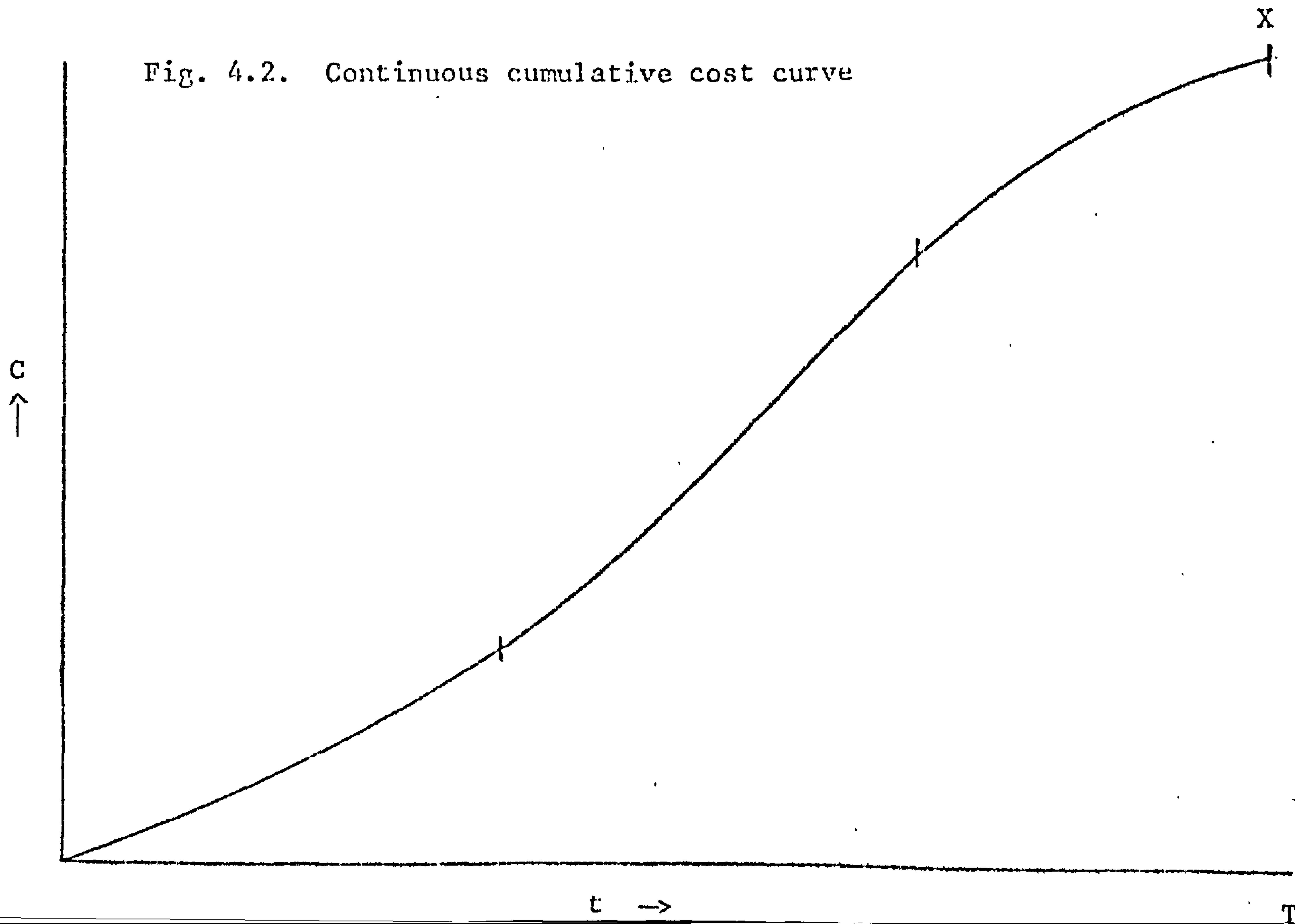
The cumulative effort/expenditure curves are usually characterised by a slow start when resources are first being deployed, a relatively rapid middle rate of execution, then a slow finish related to tidying up processes. These phases are shown in fig. 4.1

Fig. 4.1 Straight line approximation cumulative cost curve



In figure 4.1 OA represents the initial slow phase, AB the accelerated phase and BX the clearing-up phase. In practice the real world smooths the discontinuities out at points A and B and familiar S type curves result.

Fig. 4.2. Continuous cumulative cost curve



4.1.1 Keller-Singh Expenditure/Effort Forecasting Model

Keller and Singh (1975) have examined histories of a very large number of activities of different projects and derived a mathematical expression for expenditure as a function of time. They have found that a 4-parameter curve of the following form

$$C = \frac{C_\infty \, t^n \, e^{(t/\tau)^n}}{\theta + t^n e^{(t/\tau)^n}} \qquad \text{------ (1)}$$

is adequate for this purpose, where C is the cumulative expenditure of the project at any time t. The four parameters that are fitted are n, C_∞, τ, θ and are related to the nature of the project (eg. civil, mechanical etc.) total cost, total duration and the time when maximum rate of working would occur respectively.

C_∞ is the cost of the project if the project was continued for an infinite time. (ultimate cost).

τ is a parameter with the dimensions of time, related to the total duration T of the project.

θ is a parameter related to the time to when the maximum rate of working occurs, as shown in fig.4.3.

n is a parameter usually between 1 and 3 and depends upon the complexity of the project. for well defined activities such as civil works n is close to 1. However, for complex activities which involve considerable innovation of design, n can approach 3. For this reason authors have called n the 'learning parameter'.

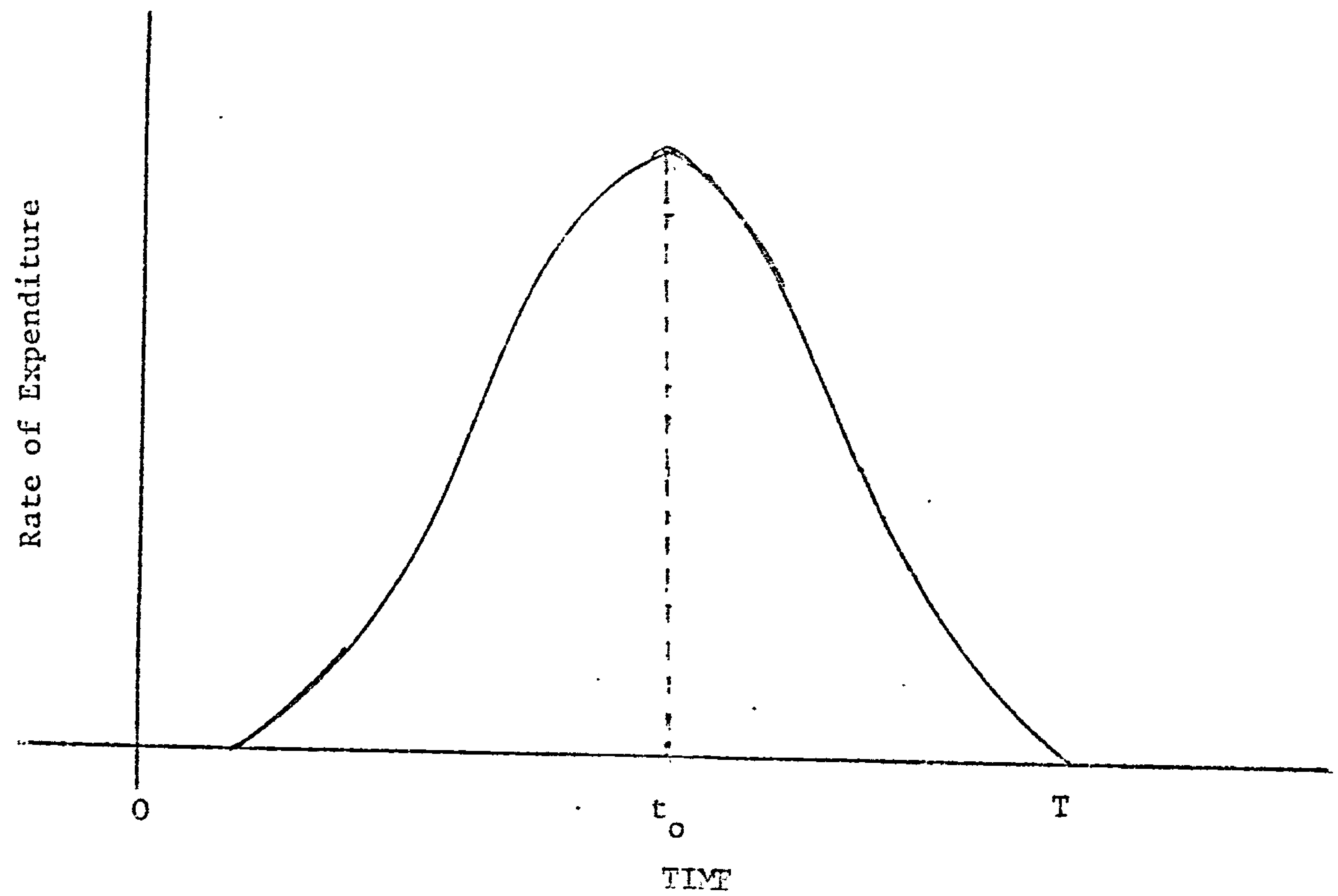


Fig 4.3 Rate of Expenditure Curve

For small values of t the Eq (1) behaves like:

$$C = \frac{C\infty\ t^{n}}{\theta} \tag{1.1}$$

If this learning parameter is unity, one also obtains initially straight line behaviour with time:

$$C = \frac{C\infty\ t}{\theta} \tag{1.2}$$

Furthermore, from (1) one sees that $C \rightarrow C\infty$ as $t \rightarrow \infty$. In mathematical sense C is the ultimate cost incurred after infinite time elapses. All activities are, however, of finite duration and the final cost C_T at the end of an activity will in principle be less than C∞. However, in the cases analysed by M. P. Singh (1978), during his research, it is found that the "rundown" is very rapid near the end of activity so that C_T is in fact a little different from C∞. Again, since in most major projects there is often a minor of "mopping up" still occurring even after the official completion of the project the constant C∞ in these cases can still be meaningfully interpreted.

By changing parameters of the Keller-Singh model it is possible to simulate any expenditure rate. The greater the value of τ, the greater the proportion of total expenditure spread over a long time period ie. models almost a constant rate of expenditure. The greater the value of Θ, the later the time at which the maximum rate of expenditure occurs. The parameter n represents the complexity of the project.

Expenditure is insensitive to the parameters τ and n. An advantage of model (1) is that the parameters n, Θ τ have a readily identifiable physical significance. It has been shown by Keller and Singh that by choosing suitable parameters for the above expression (1), one can obtain a curve which can represent a maximum rate of spending at the start, middle or end of the project.

Rate of Expenditure Curve

The rate of expenditure curve may be obtained by differentiating eg. (1)

$$\frac{dC}{dt} = \frac{C}{C_\infty} (C_\infty - C) \quad g(t) \qquad \text{------ (2)}$$

where $g(t) = \frac{n}{t} + \frac{n}{\tau} \left(\frac{t}{\tau}\right)^{n-1}$

4.1.2 Forecasting Expenditure for individual Projects

The forecasts for a new project are obtained by estimating the parameters of the model from the 'case history' of a similar project. Likewise if the data for a number of similar projects is available a set of standard parameters may be obtained for the model and these may be used to generate initial expenditure forecasting. The graph obtained can be used as an 'initial guidance' or as 'target' figures against which the actual costs of the project can initially be monitored.

When the project has been in progress for a few months, it is possible to re-determine the parameters n, τ and 0 for the project by fitting the actual available data to date in the model. If a project deviates from the original forecast, then the parameters for that project can be re-calculated and a new forecast can be made.

The model can be used when the only information available is project total cost, duration, nature of the project and the time when the rate of maximum effort will be utilized.

4.1.3 Uses of S-curve

Battersby, A. (1970) has reported that "Cumulative curves of expenditure are sometimes used on large projects as a means of monitoring time and cost simultaneously".

Pilcher, R. (1973) has described the use of S-curve as a means of preparing cash forecasts and reviewing the project requirements for working capital.

Van Steelandt & Gelderls (1979) have described a case study of financial control of network projects in a Belgian construction company. They have developed a computerized planning and control system based upon network computations and the principles of budgeting and control with cumulative S-curves.

Handa, et al (1974) have described a cost control and forecast model using an S-curve. They have found a fifth degree polynomial as the best average representation of all the data for 45 projects they have analysed.

S. H. Wearne, Pilling, and Nicoll (1966) have reported the use of S-curve in Programme Management as applied to Power Station construction. "The process of establishing a realistic programme of expenditure is an extension of the exercise of producing a realistic programme of work for the project. Recent researches by the Board have determined mathematical conventions which, when applied to agreed physical programmes and by use of the computer, can produce an accurate Incidence of Expenditure Chart or curve.

At regular intervals during the manufacturing process, the physical progress is recorded in the computer in terms of work done on each item of the contract. The computer then evaluates these and integrates them into a total value for the proportion of contract completed as at that date. Samples of the output can be shown either in the form of an 'S' curve or in the form of a statement. The statement provides the dual purpose of advising both the engineering and financial management of the current position of the contract, and assists both to start corrective action if the position is unsatisfactory".

Sandilands (1975) in his Inflation Accountancy report to the government, highlighted the need to forecast cash flows in times of inflation and thus avoid an embarassing cash deficit when replacing old equipment at new inflated costs.

Harris and McCaffer (1977) reported that "Cash flow forecasting is, like any forecasting, the result of calculation based on the information available at the time and a few assumptions as to what will happen if, as is likely, the data contained in the information changes or the assumptions alter, the forecast will be in error and a new forecast is required. When a company equips itself to forecast its cash flows efficiently and without great expense it usually forecasts every quarter, and in some cases every month.

This is sufficient to monitor the everchanging situation."

There are various possible areas and ways where the S-curve model described in the last section could be utilised. Some of these are discussed below.

a) Initial Budget Expenditure Forecasting

First of all, the total cost of a given project C_∞ is estimated, then similar past projects are used to estimate parameters η, θ and τ. Thus by using cumulative and differential cost models amount of expenditure expected at any time can readily be generated. These figures can then be used as reference against which the actual costs of the project can initially be monitored.

b) Budget Control

Since the expenditure forecasts obtained initially must by their very nature be only provisional estimates, it will be necessary from time to time to compare the forecasted expenditure with the actual expenditure. Thus final expenditure may be kept within the 'overall' ceiling figures, by up-dating the parameters of the model at periodic intervals by using the current available data. Having updated these parameters, revised budget forecasts can be easily made.

c) Preparation of Tender for Large Projects

The proposed S-curve model may be used for preparing tenders for large projects. A large project usually consists of many well defined activities, each of which may be represented by individual S-curves. By combining the curves appropriate for each activity it is possible to derive the global expenditure curve for the project. M. P. Singh (1978) has developed a method to forecast the expenditure for a large project which can be controlled and planned by network planning methods.

d) Maximising C.P.A. (Contract Price Adjustment) Claims

Most project contracts contain CPA clauses; the expenditure forecasts made from the model can be used as a basis for additional maximisation of profits of the contractor if he is able to select the submission dates of C.P.A. claims. Supriyaslip (1975) has developed one such method based upon a dynamic programming approach.

e) Risk Analysis

The model developed can also provide a basis for financial risk analysis of the projects. The main advantage of the model arises from the fact that an activity expenditure can be represented by only four parameters; this particularly eases the task of data handling and estimation.

Y. P. Gupta (1976) has developed a method using the S-curve model for the quantification of risk associated with a capital project.

f) Manpower Planning

The S-curve model can easily be adapted to provide manpower estimates for new activities or projects. Even if a suitable 'case history' does not exist, one can nevertheless, establish an 'activity' curve provided the peak manpower force on the project and the estimated time of its occurrence preferably using some additional information regarding initial force build-up.

Where a number of projects are concurrent, by combining curves appropriate for each project it is possible to establish the size of the peak manpower requirement. This could especially be useful for personnel recruitment and other deployment purposes.

P.K. Sehgal (1978) has fitted the S-curve model for the manhours worked in a design department of an engineering firm.

It was reported by Keller & Singh (1975) and also by Y.P.Gupta (1976) that, apart from project expenditure the model also fitted well on a large number of growth processes such as the number of letters sent by contractors to a client, profits of a construction company and the number of contracts won by a construction company. Benhabib (1978) found that the Keller-Singh model provided good fits to energy and growth data.

The model has already been implemented by an international company in their planning operations. Examples in the next section illustrates some of the uses described above.

4.1.4 Practical Examples

To illustrate the practical use of Keller-Singh model, two examples are presented.

1) Forecasts Deriving Expenditure from Keller-Singh Model When Historical Data For a Similar Project is Available

Consider that a client/contractor has decided to proceed with a project, or is at the stage of deciding to go ahead with a project, and suppose at this stage the information available to him is an estimate of total cost and duration of the project, and expenditure data for a similar project. He is interested to know his periodical committments over the life of the project.

In this example a project with estimated total cost of £7m and of duration 50 months is considered. The time and expenditure figures are scaled to 10 and 100 respectively. The parameters of the Keller-Singh model for expenditure data for a similar project are used as initial input.

The project considered and parameter values for the Keller-Singh curve are:-

$n=1.0$

$\tau=2.0$

$\theta=35$

$C_\infty=88$

Knowing the total cost, duration and using the parameters of Keller-Singh model for the previously analysed similar project, the initial guidance expenditure curve given in Fig.4.4 and table 4.1are obtained. (Actual figures which were obtained after the completion of the project are given as well in order to demonstrate how good the initial forecast has been).

Periodical Re-estimation of Parameters When Additional Information is Available

When the project has been in progress for some time and expenditure figures are available, the parameters of the Keller-Singh model are redetermined by fitting the model to the available data points. In this example the parameters of Keller-Singh model were redetermined by fitting the actual expenditure data available after every twelve months. Revised forecasts after periods of 12, 24 and 36 months are presented in figs. 4.5-4.8 graphically.

Table 4.2 gives a summary of the forecasts by Keller-Singh model at each stage for comparison purposes. Table 4.2 shows that Keller-Singh model has provided fairly close approximation to the actual values of the work executed. Table 4.3 gives the parameters of Keller-Singh model at each stage. In fig. 4.9 all the five curves obtained after periodical re-estimation of parameters are given.

Scaling of Parameters τ and θ

In the examples of Section 4.1.4 the time scale is chosen arbitrarily as 10 with a cost scale of 100, while in the cases of Section 4.2.4 both scales are taken as unity. Singh (1978) has shown that if a previous project of duration D_o has parameters τ_o, θ_o and n_o then the parameters for a new project of duration D of a similar shape are given by

$$\tau = \frac{D}{D}\tau_o \qquad \theta = \left(\frac{D}{D_o}\right)^{n_o} \theta_o \quad \text{and } n = n_o$$

Example :

Parameters τ and θ for second example in Section 4.1.4 can be obtained as follows : Standard Parameters for a project in cost category 7 are

$$\tau_o = 0.372 \qquad n_o = 1.2887 \qquad \theta_o = 1.288 \quad \text{where } D_o = 1$$

The parameters for a similar new project (same expenditure shape) with time scale D=10 can be obtained as

$$\tau = \frac{10}{1} \times 0.372 = 3.72 \qquad \theta = (10)^{1.2887} \times 1.288 = 25.4$$

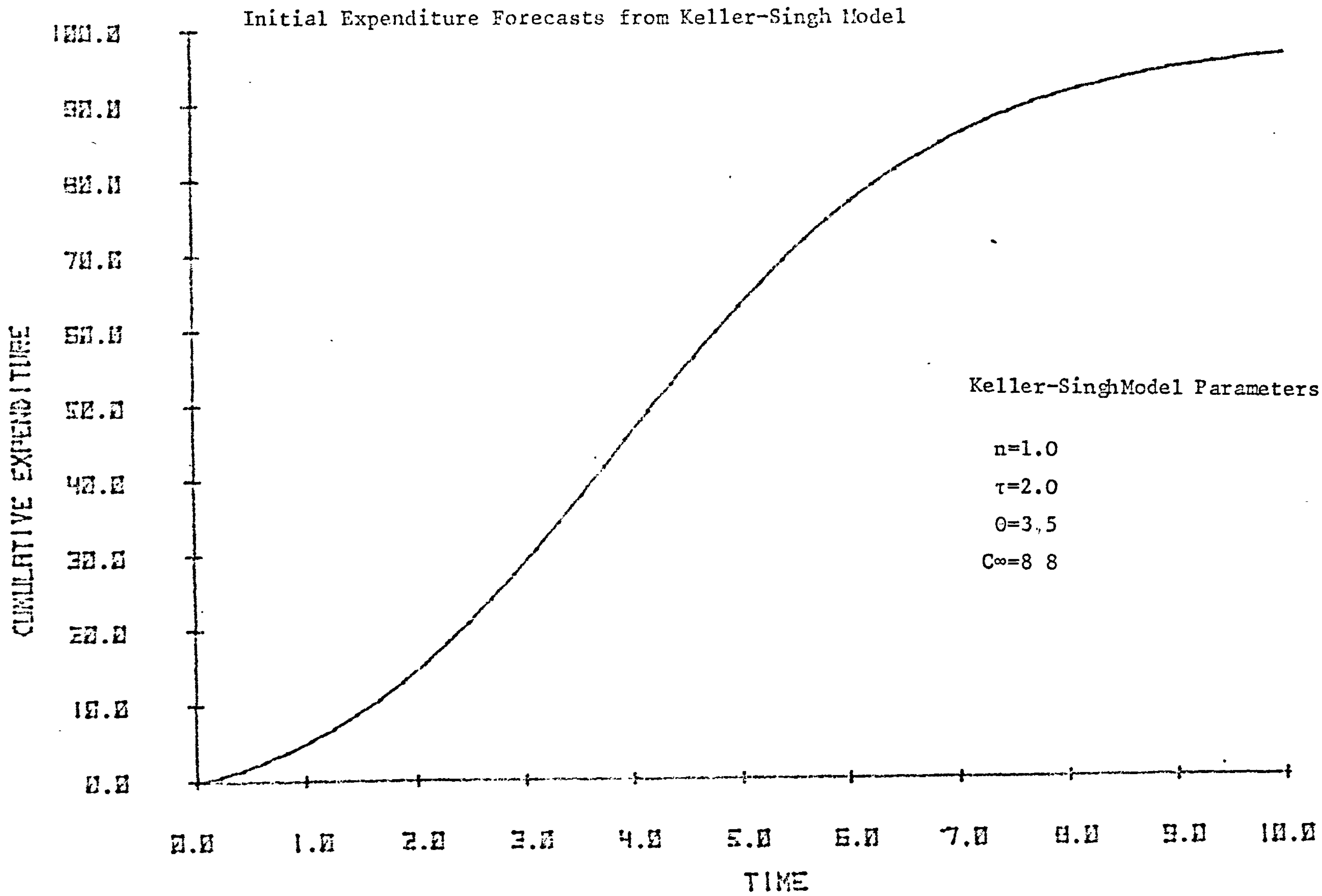
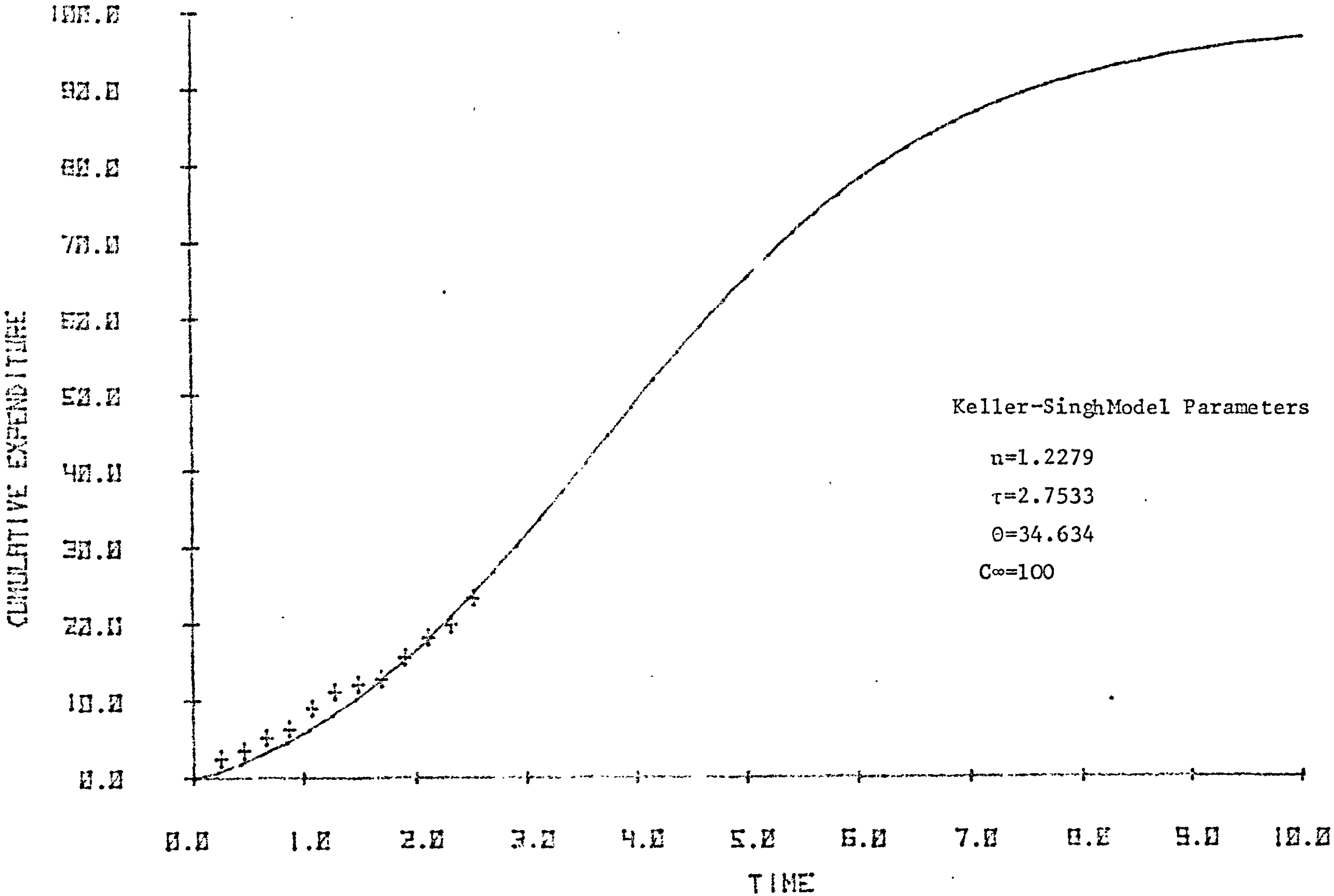

Initial Expenditure Forecasts from Keller-Singh Model
CUMULATIVE EXPENDITURE
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
TIME
Keller-SinghModel Parameters
n=1.0
τ=2.0
θ=3.5
C∞=8 8

Fig. 4.4

TABLE 4.1

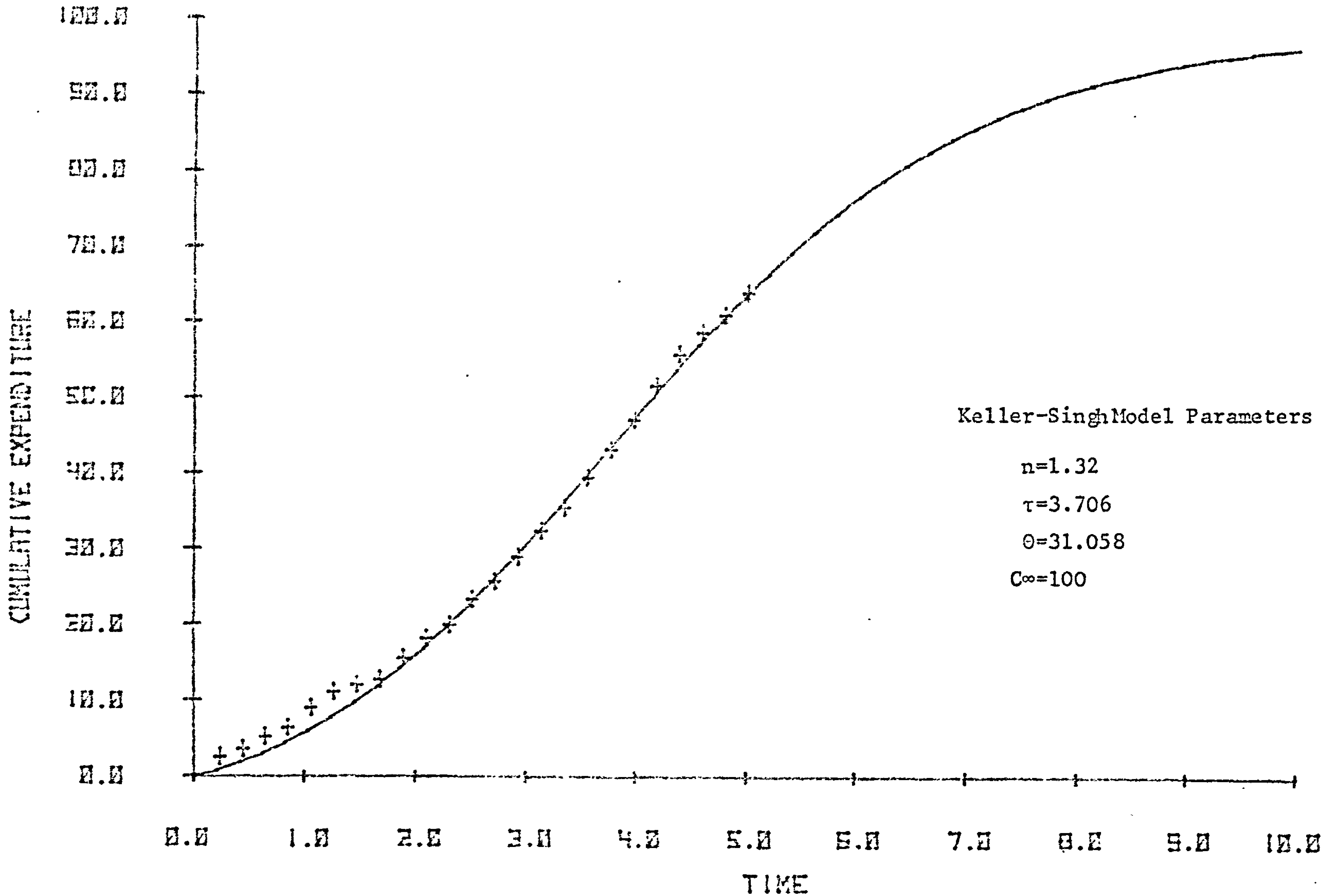
Initial Forecasts from Keller-Singh Model

Time	Cumulative Expenditure		Time	Cumulative Expenditure	
Month	Actual	Initial Forecasts from K. S. Model	Month	Actual	Initial Forecasts from K. S. model
1	61046	41143	26	4161249	4370905
2	119973	90255	27	4454287	4566759
3	202615	148277	28	4695315	4750508
4	261352	216181	29	4887842	4921786
5	340757	294936	30	5061071	5080498
6	439288	385488	31	5319273	5226778
7	540005	488720	32	5440356	5360947
8	650236	605407	33	5568608	5483473
9	734880	736173	34	5613934	5594935
10	823821	881433	35	5813664	5695981
11	972833	1041350	36	5999765	5787309
12	1174704	1215782	37	6186025	5869631
13	1313700	1404246	38	6280695	5943664
14	1534850	1605894	39	6361776	6010107
15	1692040	1819501	40	6477353	6069635
16	1830890	2043486	41	6573587	6122885
17	2084041	2275942	42	6686198	6170460
18	2283428	2514698	43	6746313	6212917
19	2554923	2757396	44	6808579	6250773
20	2862726	3001579	45	6820204	6284499
21	3034602	3244789	46	6821766	6314528
22	3283384	3344660	47	6881020	6341251
23	3534216	3719001	48	6931975	6365022
24	3777407	3945868	49	6970123	6386160
25	4000509	4163610	50	7015262	6404953



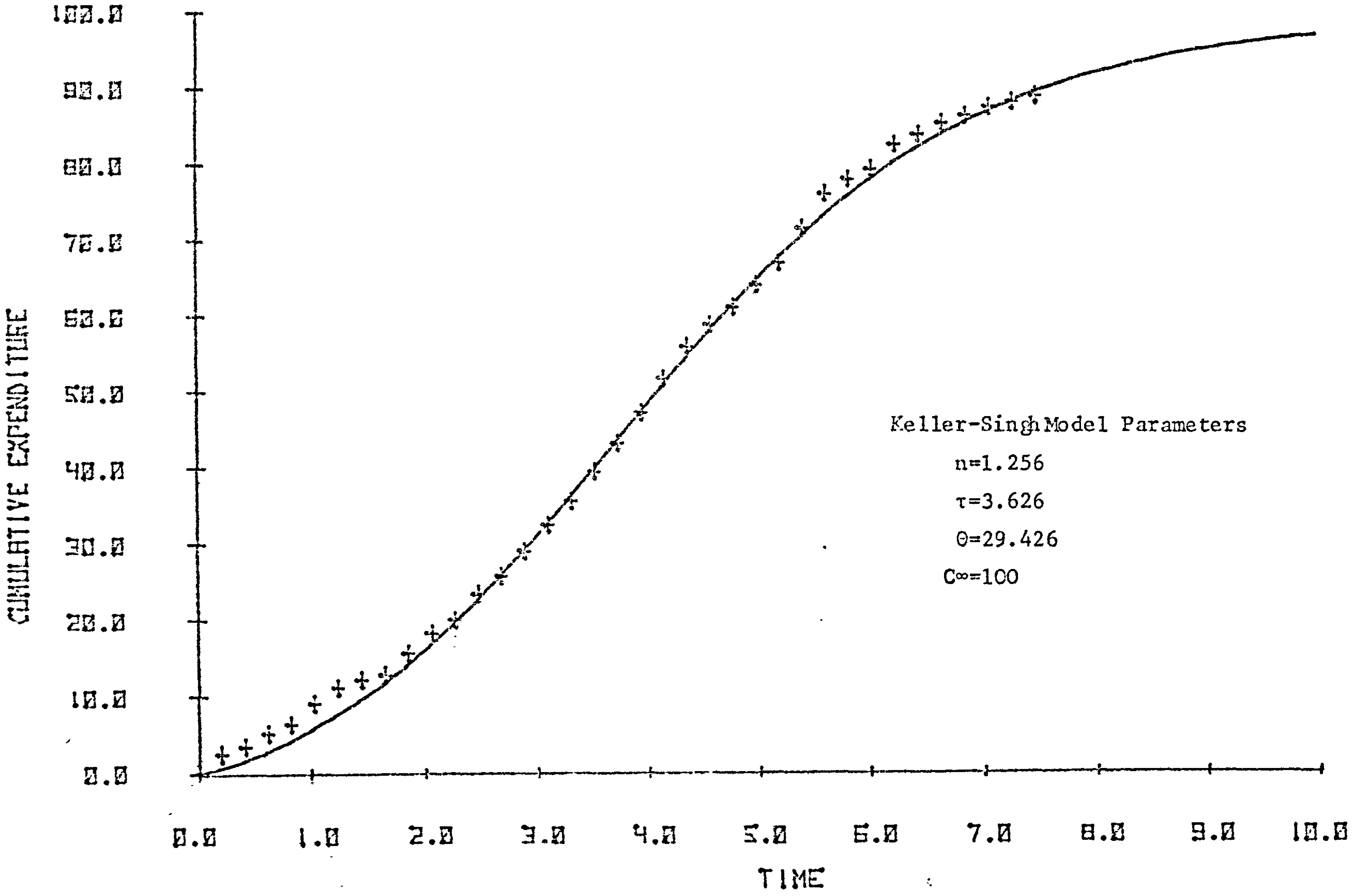
Ependiture forecasts from Keller-Sing model after fitting 12 months actual data

Fig. 4.5

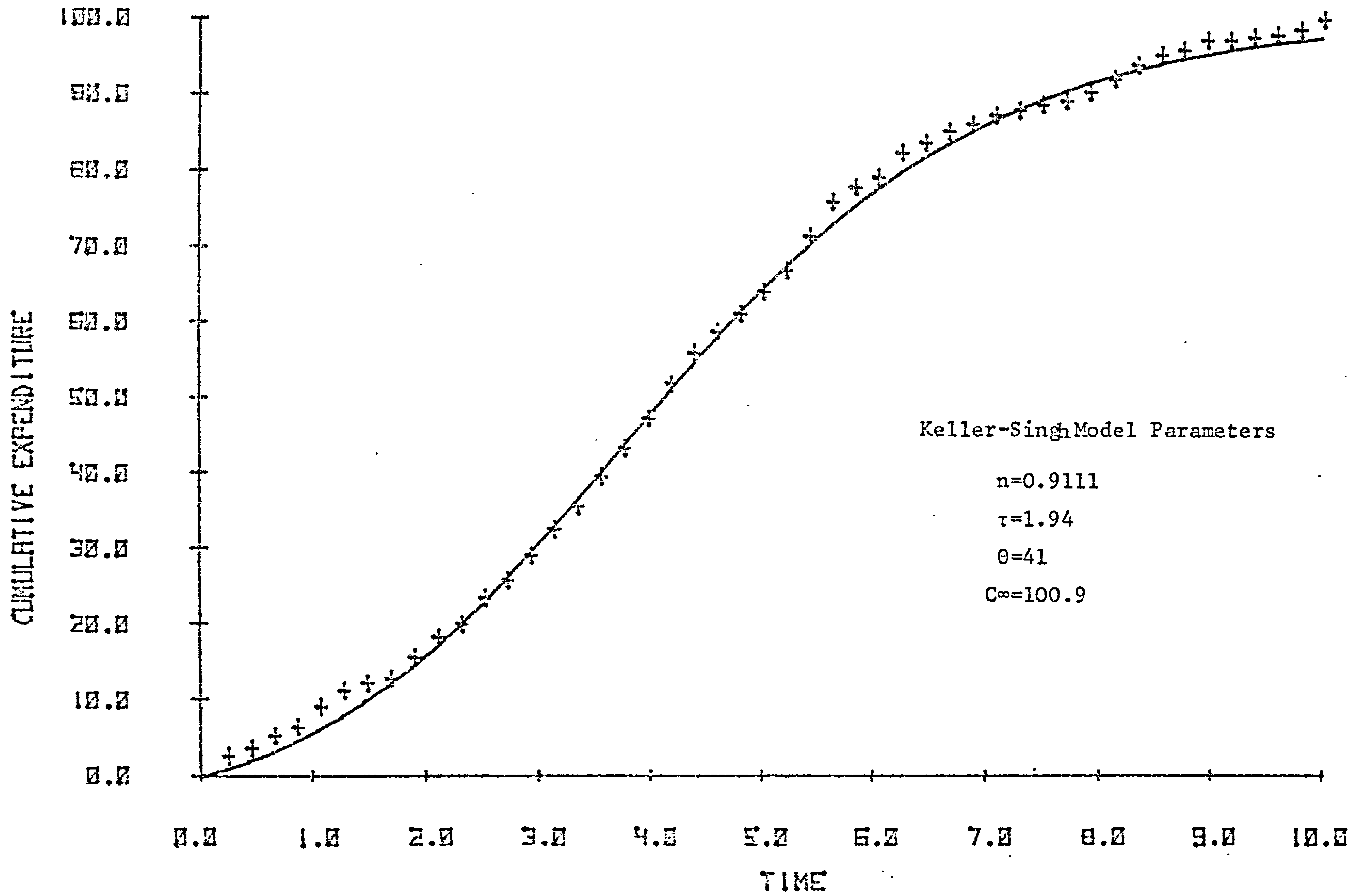


Expenditure forecasts from Keller-Singh model after fitting 24 months actual data

Fig. 4.6



Expenditure forecasts from Keller Sing model after fitting 36 months actual data



Keller-Sing model fitted to the actual data for the entire project.

Fig.4.8

Comparison of forecasts of Keller-Singh model at various stages of the project

Contract Sum = £7,450,000.   Period = 50 months

	Actual	Initial Forecast	After Fitting Actual Data For 12 Months	24 Months	36 Months	For The Entire Project
1	61046	41143	30899	29164	34291	47621
2	119973	90255	75897	74699	84349	99383
3	202615	148277	131638	131424	145108	158613
4	261352	216181	198225	198488	215815	226388
5	340757	294936	276351	275840	296451	303552
6	439288	385488	366935	363770	387251	390857
7	540005	488720	470986	462574	488554	488978
8	650236	605407	589525	572776	600719	598502
9	734880	736173	723516	694767	724077	719913
10	823821	881433	873894	828912	858892	853566
11	972833	1041350	1041042	975480	1005329	999658
12	1174704	1215782	1225621	1134611	1163428	1158211
13	1313700	1404246	1427600	1306285	1333072	1329042
14	1534850	1605894	1646641	1490288	1513973	1511749
15	1692040	1819501	1881960	1686192	1705650	1705706
16	1830890	2043486	2132289	1893336	1907424	1910053
17	2084041	2275942	2395877	2110820	2118409	2123708
18	2283428	2514698	2670511	2337503	2337527	2345387
19	2554923	2757396	2953573	2572021	2563514	2573628
20	2862726	3001579	3242130	2812809	2794948	2806829
21	3034602	3244789	3533052	3058138	3030284	3043291

Table 4.2

22	3283384	3744660	3823137	3306160	3267885	3281268
23	3534216	3819001	4109251	3554961	3506073	3519012
24	3777409	3945868	4338457	3802621	3743170	3754826
25	4000509	4163610	4678125	4047263	3977544	3987107
26	4161249	4370905	4916016	4287116	4207653	4214381
27	4454287	4566759	5160339	4520556	4432079	4435336
28	4695315	4750508	5389767	4746147	4649360	4648845
29	4887842	4921786	5603438	4962667	4859011	4853971
30	5061071	5080498	5800916	5191290	5059539	5049980
31	5319273	5226778	5982150	5364778	5250446	5236330
32	5440356	5360947	6147411	5549097	5431228	5412664
33	5568608	5483473	6297231	5721784	5601564	5578792
34	5613934	5594935	6432341	5882740	5761304	5734679
35	5813664	5695981	6553610	6032043	5910453	5880418
36	5999765	5787309	6661998	6169921	6049145	6016212
37	6186025	5869631	6758509	6296725	6177627	6142354
38	6280695	5943664	6844158	6412904	6296237	6259208
39	6361776	6010107	6919943	6518980	6405385	6367187
40	6477353	6069635	6986826	6615524	6505529	6466744
41	6573587	6122885	7045717	6703139	6597167	6558354
42	6686198	6170460	7097467	6782441	6680817	6642501
43	6746313	6212917	7142859	6854048	6757005	6719672
44	6808579	6250773	7182614	6918566	6826255	6790349

Table 4.2

45	6820204	6284499	7217383	6976582	6889086	6854999
46	6821766	6314528	7247756	7028659	6945996	6914075
47	6881020	6341251	7274260	7075328	6997467	6968007
48	6931975	6365022	7297365	7117091	7043955	7017205
49	6970123	6386168	7317493	7154413	7085891	7062054
50	7015262	6404953	7335013	7187727	7123678	7102916

Table 4.2

Parameters of Keller-Singh model at various stages of the project

	n	τ	θ	C^∞
Initial Estimate of Parameters	1.0	2.0	35	88
Parameters obtained after fitting				
first 12 months expenditure data	1.2279	2.7533	34.634	100
" 24 " " "	1.32	3.706	31.058	100
" 36 " " "	1.256	3.626	29.426	100
" 48 " " "	0.9111	1.94	41	100.9

Contract sum = £7450000

Contract period = 50 months

Table 4.3

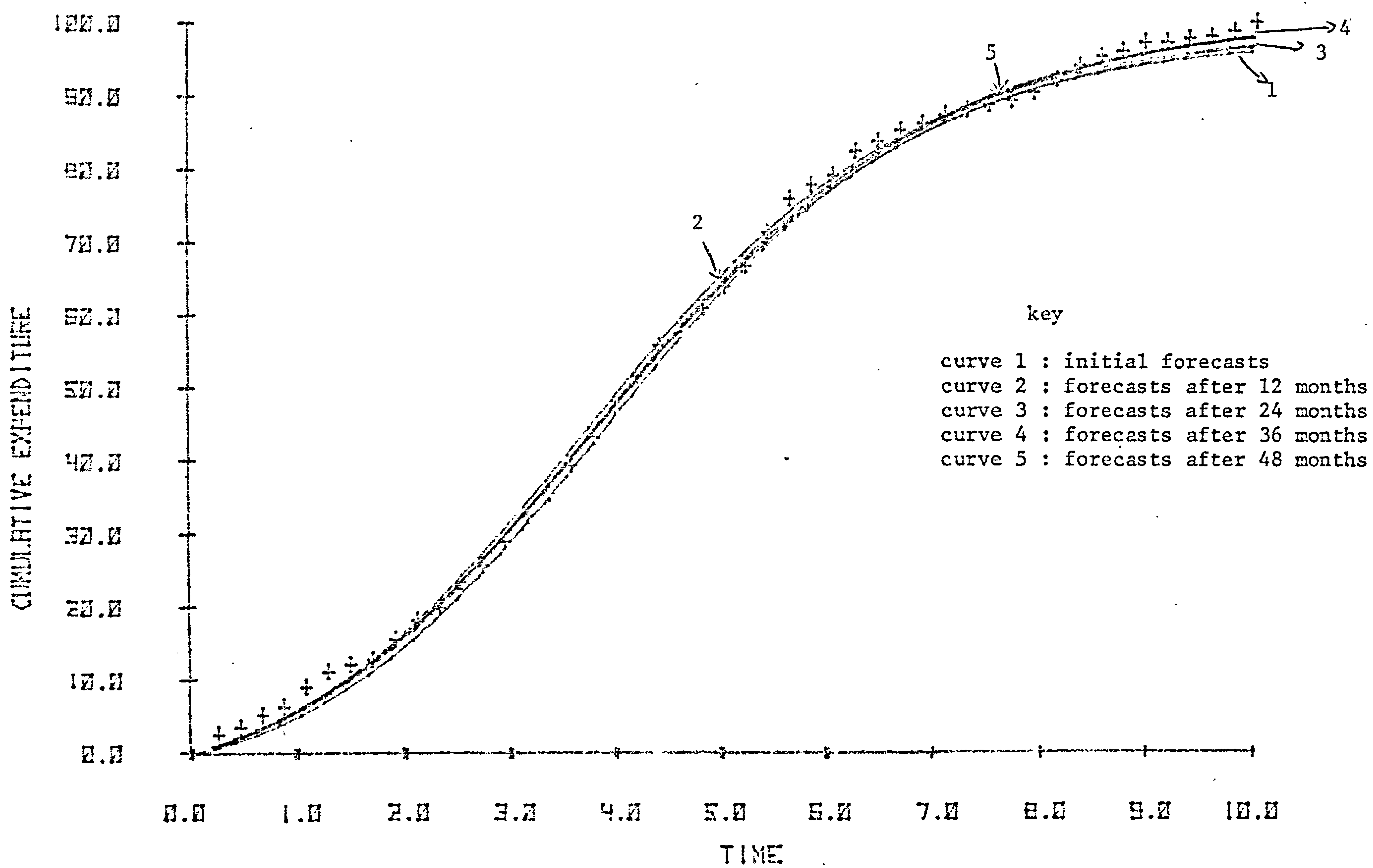


Fig. 4.9

Keller-Sing model curves at various stages of the project fitted to the actual data

2) <u>Example showing the forecasts from Keller-Singh model when historical data of a similar project is not available.</u>

The Keller-Singh model is also capable of producing expenditure curves when historical data for a similar project is not available, and the only information available is total cost, total duration and the time when the maximum rate of expenditure is expected to occur.

The initial values of Keller-Singh model parameters can be assumed depending on the above information and nature of the project.

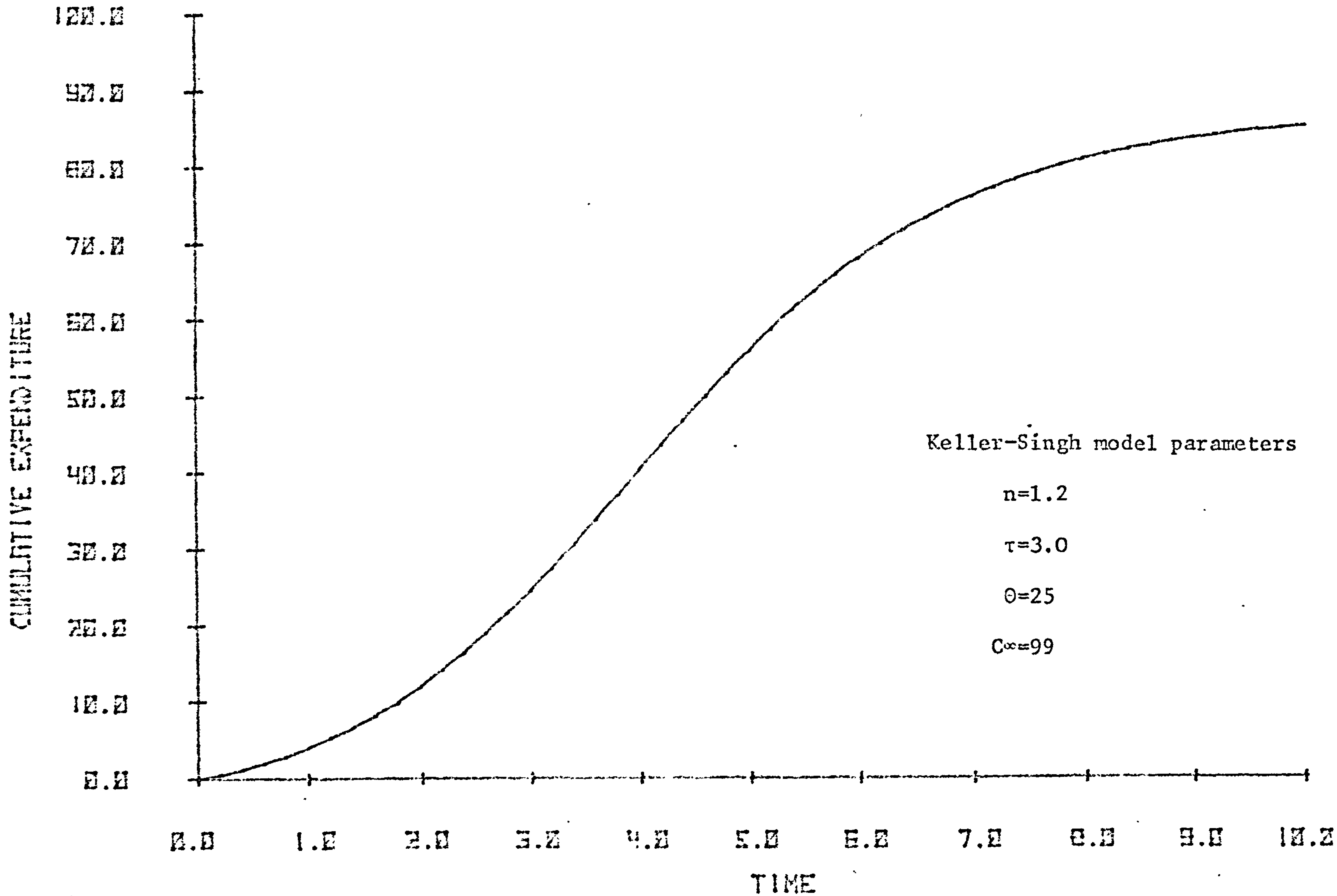
In the given example a project with an estimated total cost of about £4m and duration <u>48</u> months has been considered. For the purpose of keeping the computational errors within limits these figures have been scaled to 100 and 10 unit respectively.

The initial estimates of the parameters of the Keller-Singh model are:

$n=1.2$
$\tau=3.0$
$\theta=2.5$
$C_\infty=99$

The forecasts generated from these initial estimates of parameters are given in fig. 4.10 and table 4.4.

Later, when the actual expenditure data on the project was made available, the parameters of Keller-Singh model were re-estimated and new forecasts were made after every 12 months. Revised forecasts after fitting actual expenditure data for 12, 24 and 36 months are presented in figs. 4.11 - 4.24 graphically.



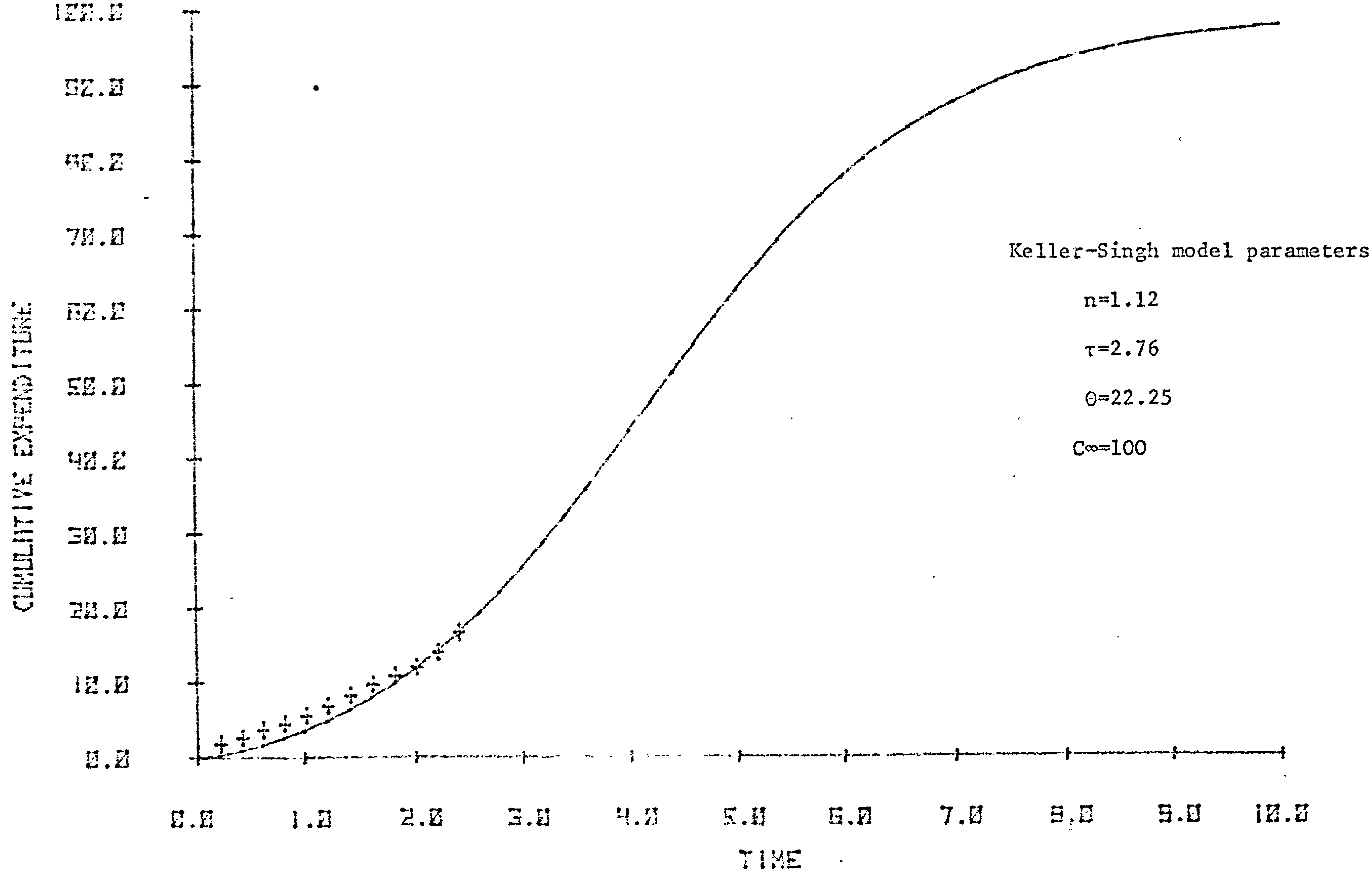
Initial Expenditure Forecast from Keller-Singh Model

Fig. 4.10.

TABLE 4.4

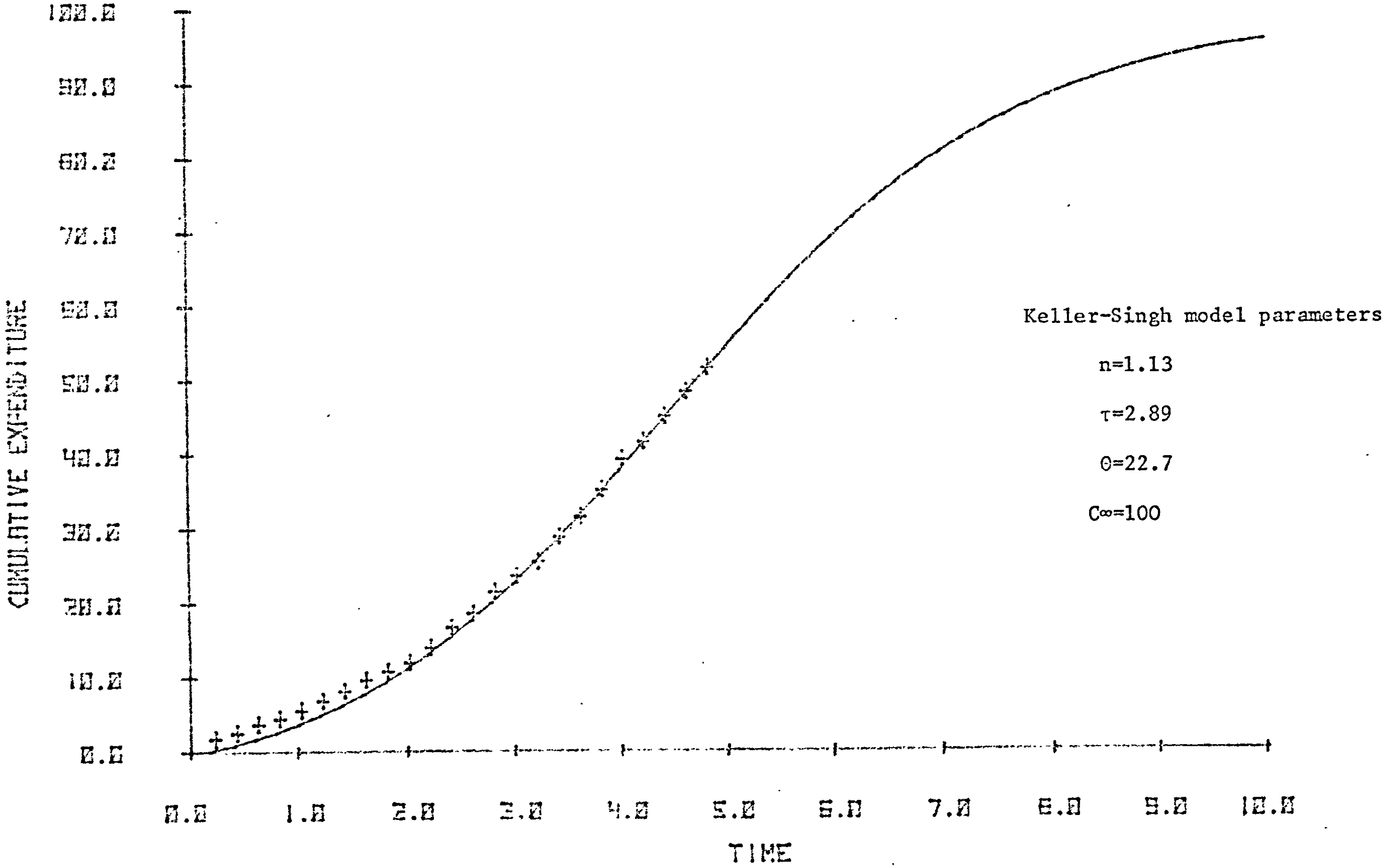
Initial Forecasts from Keller-Singh Model

	Cumulative Expenditure			Cumulative Expenditure	
Time in Months	Actual	Initial Forecasts from K.S. model	Time in Months	Actual	Initial Forecasts from K.S. model
1	64551	26151	25	2771367	2772516
2	105260	62776	26	2965307	2898567
3	176238	107112	27	3159102	3016918
4	224734	159006	28	3240341	3127286
5	338215	218696	29	3296752	3229564
6	427072	286507	30	3433976	3323800
7	468884	362803	31	3491675	3410168
8	495688	447872	32	3553710	3488948
9	613069	541910	33	3595092	3560496
10	722189	644981	34	3645442	3625223
11	795260	756980	35	3673151	3683575
12	939757	877613	36	3704993	3736017
13	1038326	1006374	37	3725806	3783017
14	1177693	1142539	38	3774855	3825034
15	1322537	1285170	39	3848377	3862517
16	1451982	1433130	40	3926525	3895889
17	1617215	1585116	41	3981209	3925551
18	1771579	1739699	42	4009177	3951876
19	1937986	1895374	43	4061599	3975208
20	2128196	2050620	44	4062019	3995865
21	2304413	2203951	45	4081743	4014133
22	2424495	2353975	46	4094578	4030276
23	2524858	2499434	47	4125164	4044528
24	2650210	2639244	48	4179164	4057104



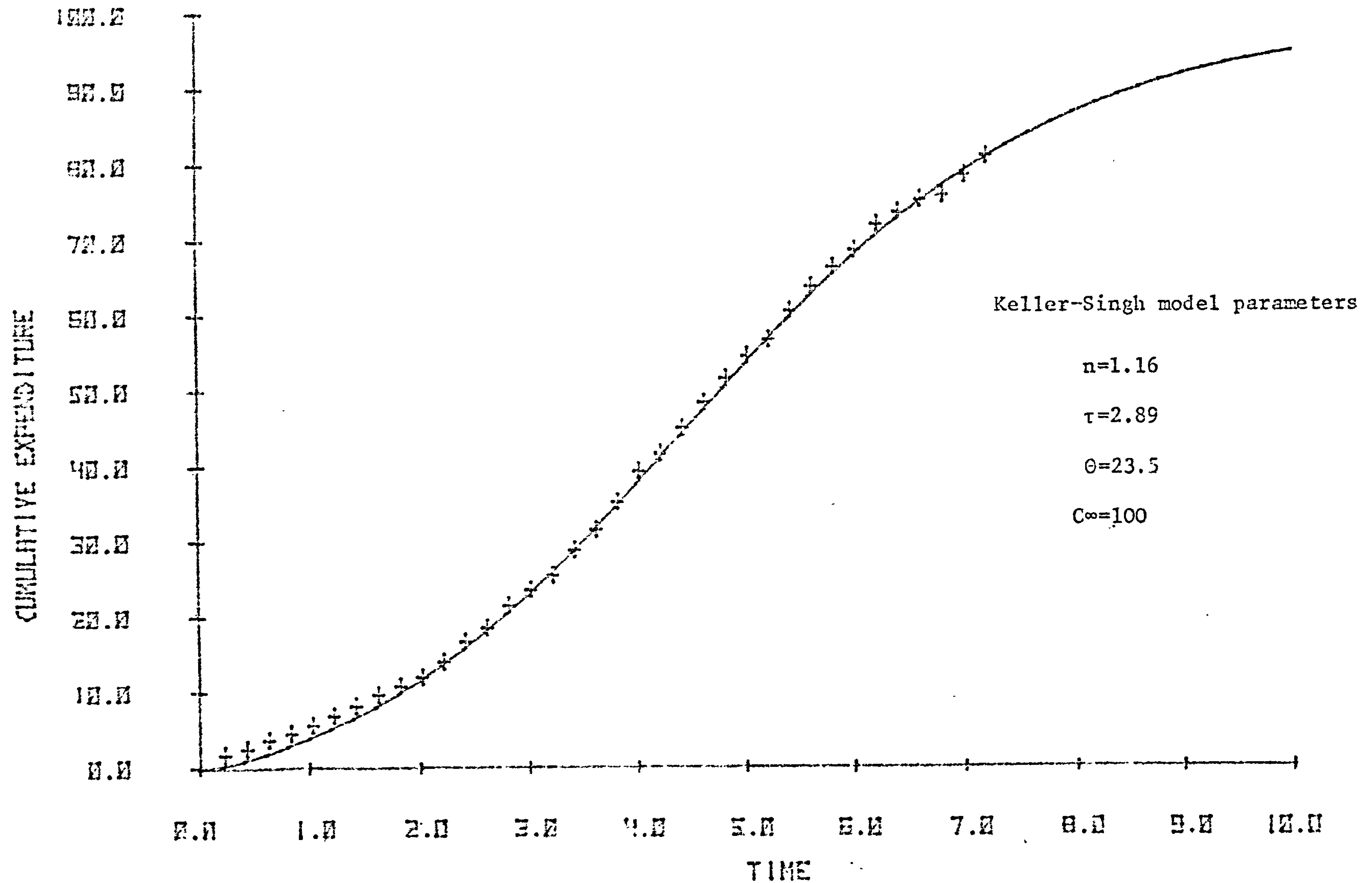
Expenditure forecasts from Keller-Singh model after fitting 12 months actual data

Fig. 4.11



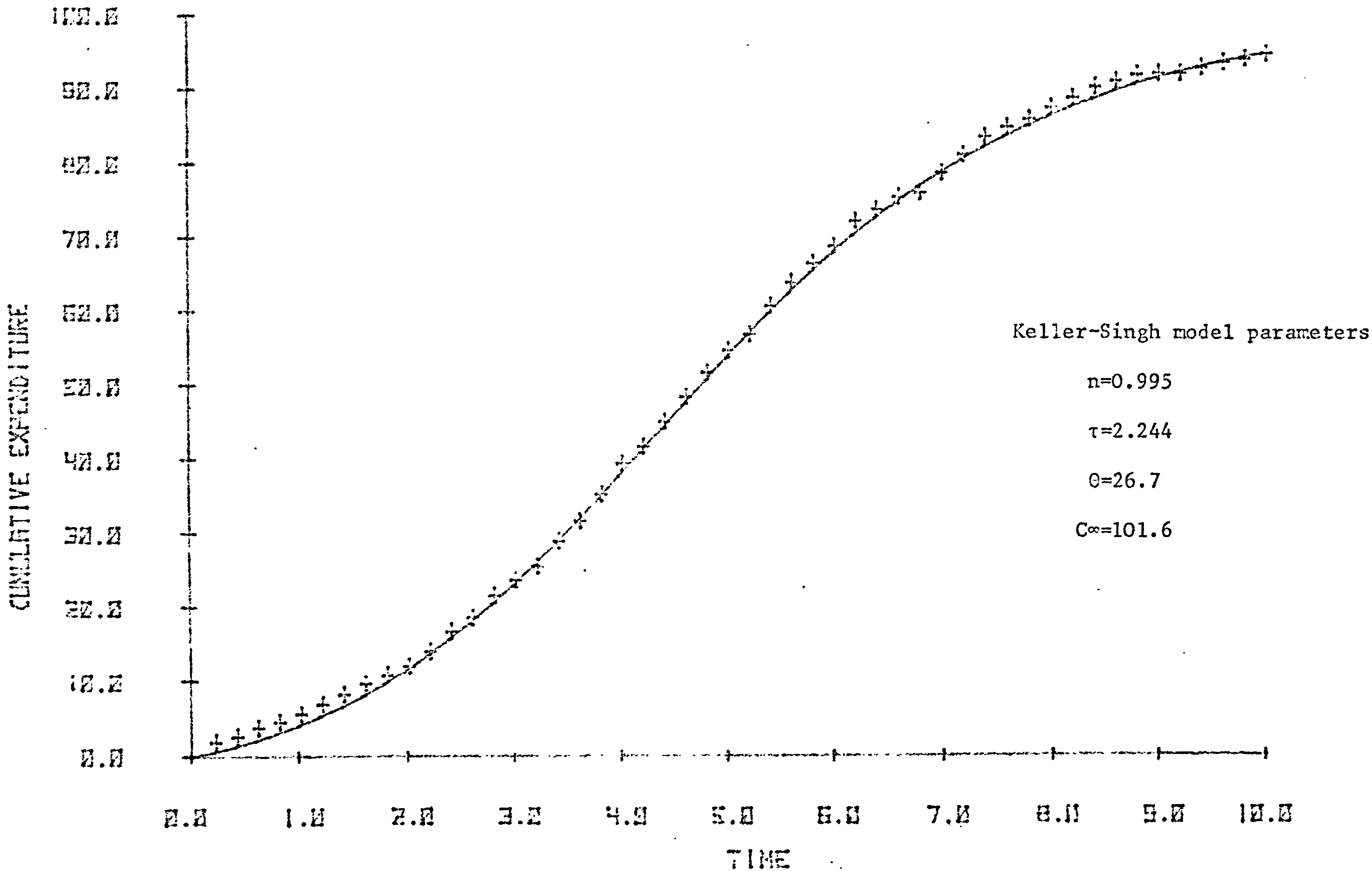
Expenditure forecasts from Keller-Singh model after fitting 24 months actual data

Fig.4.12



Expenditure forecasts from Keller-Singh model after fitting 36 months actual data

Fig. 4.13



Keller-Singh model fitted to the actual data for the entire project

Fig.4.14

Comparison of forecasts from Keller-Sing model at various stages of the project

Contract sum = £4,191,139. Period = 48 Months.

Time In Months.	Actual	Initial Forecast	After 12 Months	After 24 Months	After 36 Months	After 48 Months
1	64551	26151	34139	32701	30106	36496
2	105250	62776	78283	75331	70615	79047
3	176238	107112	130373	125627	118993	128339
4	224734	159006	190444	183541	175164	184938
5	338215	218690	258779	249301	239376	249359
6	427072	286507	335688	323182	311954	322046
7	468884	362803	421430	405427	393200	403355
8	495688	447872	516165	496195	483340	493519
9	613069	541910	619911	595528	582483	592629
10	722189	644981	732518	703323	690589	700605
11	795260	756980	853644	819309	807435	817178
12	939757	877613	982744	943031	932603	941879
13	1038326	1006374	1119061	1073850	1065464	1074029
14	1177693	1142539	1261638	1210939	1205177	1212754
15	1322527	1285170	1409336	1353301	1350706	1356995
16	1451982	1433130	1560869	1499793	1500838	1505542
17	1617215	1585511	1714839	1649158	1654224	1657070
18	1771579	1739699	1869794	1800068	1809422	1810183
19	1937986	1895374	2024274	1951165	1964949	1963468

Table 4.5

20	2128196	2050620	2176862	2101114	2119338	2115539
21	2304413	2203951	2326239	2248641	2271183	2265087
22	2424495	2353975	2471216	2392573	2419195	2410919
23	2524858	2499434	2610770	2531875	2562233	2551988
24	2650210	2639244	2744060	2665665	2699332	2687413
25	2771367	2772516	2870437	2793233	2829723	2816493
26	2965307	2898567	2989441	2914042	2952832	2938707
27	3159102	3016918	3100793	3027723	3068278	3053705
28	3240341	3127286	3204377	3134068	3175856	3161298
29	3296752	3229564	3300218	3233008	3275523	3261439
30	3433976	3323800	3388463	3324600	3367371	3354202
31	349165	3410168	3469355	3409004	3451706	3439763
32	3553716	3477847	3543211	3486463	3528520	3518375
33	3595092	3560496	3610401	3557283	3598473	3590354
34	364552	3625223	3671332	3621814	3661871	3656055
35	3673151	3683575	3726428	3680437	3719145	3715862
36	3704993	3736017	3776123	3733551	3770741	3770173
37	3725806	3783017	3820846	3781557	3817107	3819387
38	3774855	3825034	3861016	3824854	3858678	3863901

Table 4.5

39	3848377	3862517	3897033	3862830	3895880	3904098
40	3926525	3895889	3929278	3898859	3929113	3940347
41	3981209	3925551	3958108	3930294	3958755	3972996
42	4009177	3951876	3983855	3958569	3985161	4002372
43	4061599	3975208	4116827	3983692	4008656	4028781
44	4062019	3995865	4027304	4006251	4029540	4052505
45	4081743	4014133	4045545	4026411	4048087	4073804
46	4094578	4030276	4061783	404413	4064545	4092916
47	4125164	4044528	4076231	4060478	4079141	4110060
48	4179164	4057104	4089079	4074808	4092078	4125432

Table 4.5

Parameters of Keller-Singh model at various stages of the project

	n	τ	θ	C_∞
Initial Estimate of Parameters	1.2	3.0	25	99
Parameters obtained after fitting first 12 months expenditure data.	1.12	2.76	22.25	100
24 months " "	1.13	2.89	22.7	100
36 months " "	1.16	2.89	23.5	100
48 months " "	0.995	2.244	26.7	101.6

Contract sum = £4191139

Contract period = 48 months

Table 4.6

Keller-Singh model curves at various stages of the project fitted to the actual data

Fig. 4.15

Table 4.5 summarises the forecasts using Keller-Singh model at each stage for comparison. Table 4.6 shows that the initial forecasts are not bad in comparison with actual figures. However, the values obtained after fitting first 24 months expenditure data are reasonably close to the actual values.

Table 4.6 gives the parameters of Keller-Singh model at each stage. In fig. 4.15 all the five curves obtained after periodical re-estimation of parameters are given.

4.2 Comparison with Other Expenditure Forecasting Models

M. P. Singh (1978) has compared the Keller-Singh model with a S-curve model suggested by Nordon (1964) and found that the Keller-Singh model provided a better fit for the case studies considered. Sehgal (1978) has compared the Keller-Singh model with Gompertz and logistic curve models and has reported that whilst the Gompertz and logistic curves fit adequately the Keller-Singh model fits significantly better in most of the cases.

In the present study an attempt has been made to compare Keller-Singh model with the one used by the D.H.S.S (K.W.Hudson, 1978).

The data for the expenditure on twentyone recent schemes was provided by the D.H.S.S.

4.2.1 D.H.S.S. Expenditure Forecasting Method

The equation of the S-curve proposed by D.H.S.S is

$$y=s[x + Cx^2 - Cx - \frac{1}{K} (6x^3-9x^2 + 3x)]$$

where

y= cumulative monthly value of work executed before deduction of retention moneys or addition of fluctuations.

s= contract sum

C and K parameters

$$x = \frac{\text{month (m) in which expenditure y occurs}}{\text{contract period (p)}}$$

(i.e. proportion of contract completed)

D.H.S.S. have analysed a number of schemes and for initial guidance a list of values of standard C and K parameters has been obtained for different cost categories given in table 4.13.

By changing C and K it is possible to represent any expenditure rate; increasing C gives a slower build-up and shorter run-down period, while decreasing C gives a faster build-up and longer run-down period. Changing C has very little effect on the rate of expenditure over the central portion of the graph.

Increasing K produces a slower rate of expenditure over the central portion of the graph, with a faster build-up and shorter run-down period. Decreasing K gives a faster rate of expenditure over the central portion of the graph, with a slower build-up and longer run-down period.

4.2.2 Comparison of Keller-Singh & D.H.S.S. Expenditure Forecasting Models

The study is divided in two parts. First both the models were fitted to actual expenditure data for 21 projects, in order to know which model has generally a better fit to the actual data. Then a standard set of parameters for Keller-Singh model was obtained for different cost category. Forecasts were made from both the models with their standard set of parameters and were compared to a typical project's actual data of the same category.

For reasons of confidentiality, the total project time and expenditure for all the projects has been sealed to unity.

4.2.3 Method

The time and cumulative expenditure for each project were fitted to the Keller-Singh and D.H.S.S. models. The parameters for the best fit of the two models were estimated using the method of least squares. A computer program CURFIT of the University of Bradford Computer Centre Library was used for this purpose. The program uses a NAG routine based on a Quasi-Newton algorithm for minimisation of a given function. The program fits the data points to the model by varying its parameters until the sum of squares of the differences between the actual and theoretical values is reduced to a minimum. Our computer program in FORTRAN was developed for the processing of the data and was stored in a file to be used as an input to the CURFIT package. Another computer program in FORTRAN was developed for making forecasts from the two models and for graphical output.

4.2.4 Results

The actual expenditure data points and the corresponding best fit curves for the two models for each project are given in figures 4.16 - 4.36.

The cost of the projects analysed ranges from £½m - 7.5m and duration 2-6 years. The total cost, duration and corresponding cost category of the projects are given in table 4.7.

The best fit parameters of Keller-Singh and D.H.S.S model are given in tables 4.8 and 4.9 respectively.

Final sum of squares, root mean square values and Maximum Absolute Deviation for the best fit curves of the two models for each project are given in tables 4.10, 4.11 and 4.12 respectively.

A set of standard parameters for the Keller-Singh model for the projects of different cost category is given in table 4.13 with the corresponding set of standard parameters corresponds to the D.H.S.S. model.

4.2.5 Criteria for the goodness of fit

The criteria for the purpose of goodness of fit and comparison between the two models are

1. Final sum of the squares of Absolute Differences between theoretical and empirical values.
2. Root Mean Square Values
3. Maximum Absolute Deviation

Table 4.7

Project

S. No	Total Cost	Total Time	Cost Category
1	£820000	28 months	5
2	£1268027	40 months	5
3	£2665833	51 months	6
4	£3086697	27 months	6
5	£4191139	47 months	7
6	£4500000	55 months	7
7	£5119400	72 months	7
8	£5873750	57 months	7
9	£4729665	34 months	7
10	£5076153	60 months	7
11	£4792210	53 months	7
12	£5125000	60 months	7
13	£5500000	55 months	7
14	£4200000	48 months	7
15	£5674563	58 months	8
16	£6468569	77 months	8
17	£5939330	50 months	8
18	£6047500	45 months	8
19	£6450000	42 months	8
20	£7100000	64 months	8
21	£7100000	50 months	8

Project cost	cost category
£½M - £2M	5
£2M - £3.5M	6
£3.5M - £5.5M	7
£5.5M - £7.5M	8

Table 4.8

Best fit parameters of Keller-Singh model

Project S. No	τ	n	c
1	0.45	1.72	1.0879
2	0.55	1.288	1.47
3	0.563	1.537	0.784
4	0.5667	1.553	0.9124
5	0.2934	1.451	1.6976
6	0.6567	1.8166	0.4925
7	0.08837	0.7176	1.27
8	0.4903	1.547	1.033
9	0.52	1.50696	1.02187
10	0.2655	1.0627	2.43
11	0.2156	0.9256	1.679
12	0.425	1.4987	0.797
13	0.471	1.512	0.7925
14	0.2876	1.149	1.662
15	0.442	1.4817	1.0689
16	0.4957	1.6876	0.3476
17	0.433	1.482	0.849
18	0.4606	1.5457	1.126
19	0.492	1.5755	1.5
20	0.437	1.6139	1.154
21	0.4337	1.5186	0.92399
Mean	0.4327461	1.4234838	1.1475838
STD.DEV.	0.1336	0.27504	0.47

Table 4.9

Best fit parameters of DHSS model

Project S. No	C	K
1	0.051	2.54
2	0.475	10.0
3	0.062	5.5365
4	0.217	5.972
5	-0.383	3.532
6	0.02159	4.2169
7	-0.452	3.793
8	0.103	3.9
9	0.166	5.63
10	-0.24	3.68
11	-0.798	7.718
12	-0.344	3.013
13	-0.191	3.51
14	-0.4316	3.512
15	-0.0429	3.3275
16	-0.6778	3.7065
17	-0.2823	3.211
18	0.06231	3.54
19	0.4305	5.565
20	0.2	3.915
21	-0.184	2.956
Mean	-0.1063728	4.42
STD.DEV.	-0.337	1.736

Table 4.10

Final sum of squares of Absolute Differences

between Empirical and Theoretical values

Project S. No	Keller-Singh Model	DHSS Model
1	0.023619	0.023734
2	0.0922	0.0707
3	0.02516	0.01142
4	0.007117	0.0066
5	0.00622	0.0252
6	0.00419	0.0247
7	0.00636	0.0843
8	0.0245	0.0085
9	0.036	0.0077
10	0.03155	0.0802
11	0.00716	0.0494
12	0.0067	0.0225
13	0.01005	0.0066
14	0.00645	0.0385
15	0.0212	0.0213
16	0.0033	0.08147
17	0.0277	0.0067
18	0.0543	0.0228
19	0.0318	0.0175
20	0.0525	0.0129
21	0.0052	0.0116
Mean	0.04676	0.0307344
STD.DEV.	0.0807	0.026706

Table 4.11

Root Mean Square Values

Project S.No	Keller-Singh Model	DHSS Model
1	0.029	0.029
2	0.048	0.042
3	0.0224	0.015
4	0.0162	0.0156
5	0.0115	0.027
6	0.0087	0.0212
7	0.0094	0.0373
8	0.02	0.0122
9	0.0326	0.15397
10	0.0495	0.0366
11	0.011	0.0292
12	0.0106	0.01939
13	0.0135	0.0109
14	0.0116	0.028
15	0.019	0.019
16	0.0065	0.0325
17	0.0235	0.0116
18	0.0347	0.0225
19	0.0275	0.0204
20	0.0286	0.014
21	0.0102	0.0152
Mean	0.0211	0.0289
STD.DEV.	0.01249	0.02934

Table 4.12

Maximum Absolute Deviation

Project S.No	Keller-Singh Model	DHSS Model
1	0.053	0.056
2	0.0143	0.410
3	0.0457	0.034
4	0.0457	0.033
5	0.027	0.054
6	0.0165	0.0419
7	0.0271	0.0505
8	0.056	0.0501
9	0.0605	0.03099
10	0.0517	0.0799
11	0.024	0.0639
12	0.0238	0.0414
13	0.0292	0.024
14	0.0268	0.0571
15	0.0368	0.072
16	0.0142	0.0565
17	0.0474	0.0369
18	0.0615	0.0399
19	0.046	0.0352
20	0.049	0.0285
21	0.0257	0.0288
Mean	0.0372	0.061647
STD.DEV.	0.0154	0.0309856

Set of Standard Parameters

Project Cost Category	Keller-Singh Model				D.H.S.S. Model*		Project Cost Category
		τ	n	θ	C	K	
5	Mean	0.5	1.504	1.27895	-0.145	3.595	5
	Std.Dev	0.05	0.305	0.27			
6	Mean	0.565	1.545	0.848	-0.145	3.595	6
	Std.Dev	0.0026	0.0113	0.091			
7	Mean	0.372	1.2887	1.288	0.11	3.93	7
	Std.Dev	0.1697	0.339	0.579			
8	Mean	0.463	1.558	0.9956	0.159	3.78	8
	Std.Dev.	0.028	0.075	0.353			

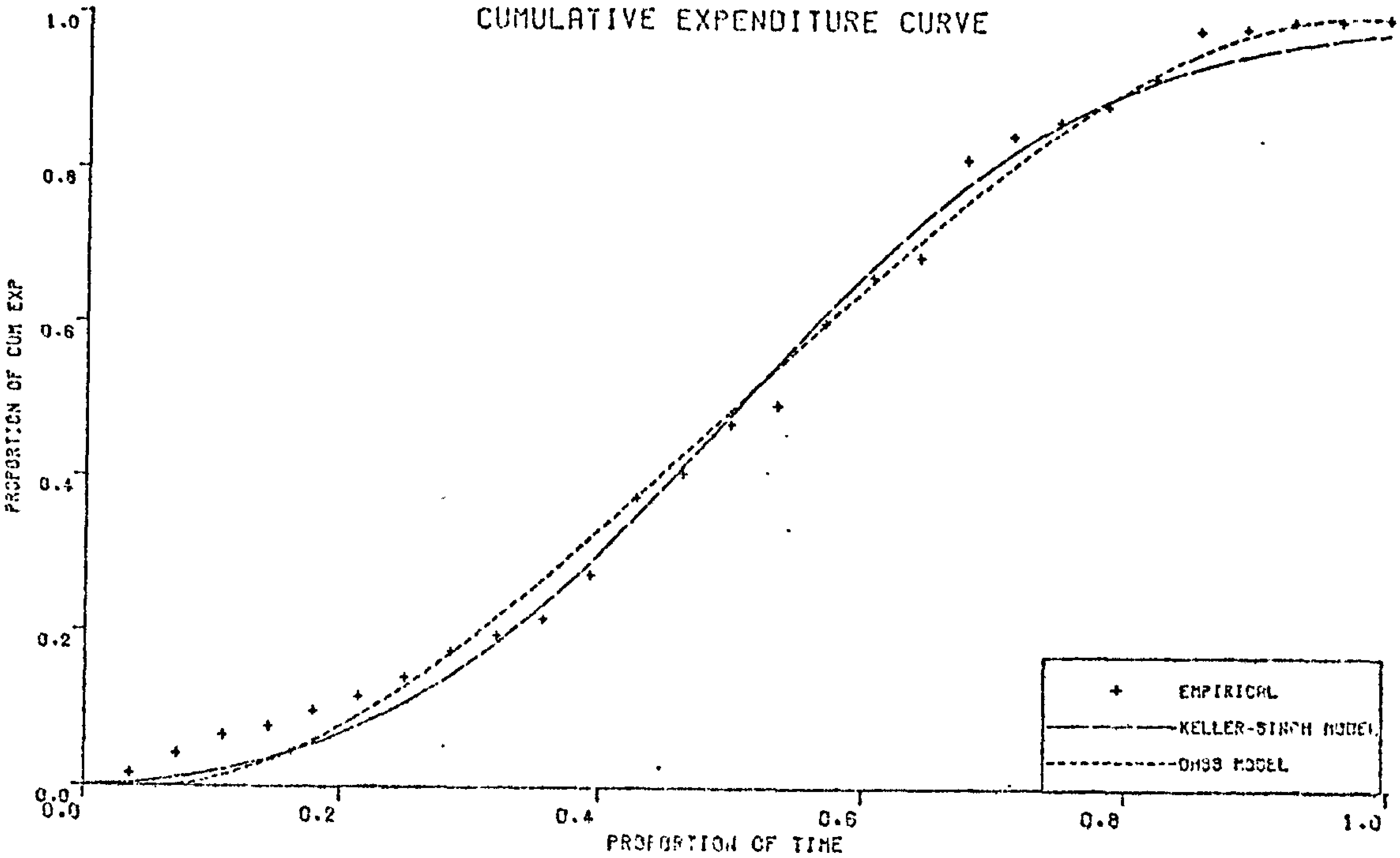
* This set of standard parameters was obtained by D.H.S.S. after analyzing a larger number of projects

Table 4.13

Range of Parameters Values

	Keller-Singh Model			D.H.S.S. Model	
	τ	n	θ	C	K
Minimum	0.2156	0.93	0.4925	-0.798	2.54
Maximum	0.6567	1.817	2.43	0.638	10.0
Mean	0.4327	1.4235	1.1476	-0.10634	4.42

Table 4.14

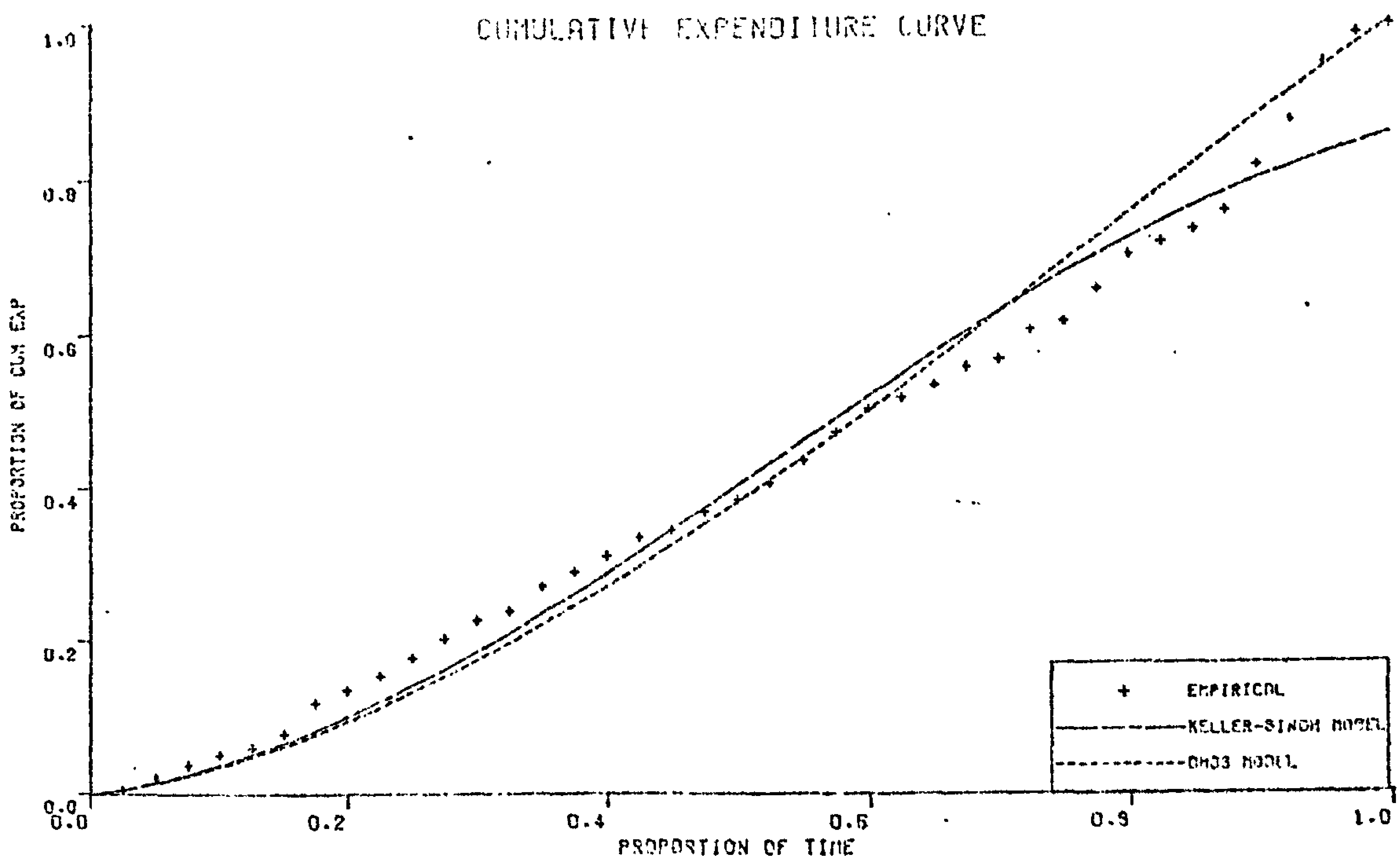


Project cost £820000 Duration 28 months Cost category 5

Best fit parameters Keller-Singh model τ=0.45, n=1.72, Q=1.0379

D.H.S.S. model C =0.051, K=2.54

Fig.4.16 Empirical Data fitted to Keller-Singh & D.H.S.S. models for Project 1

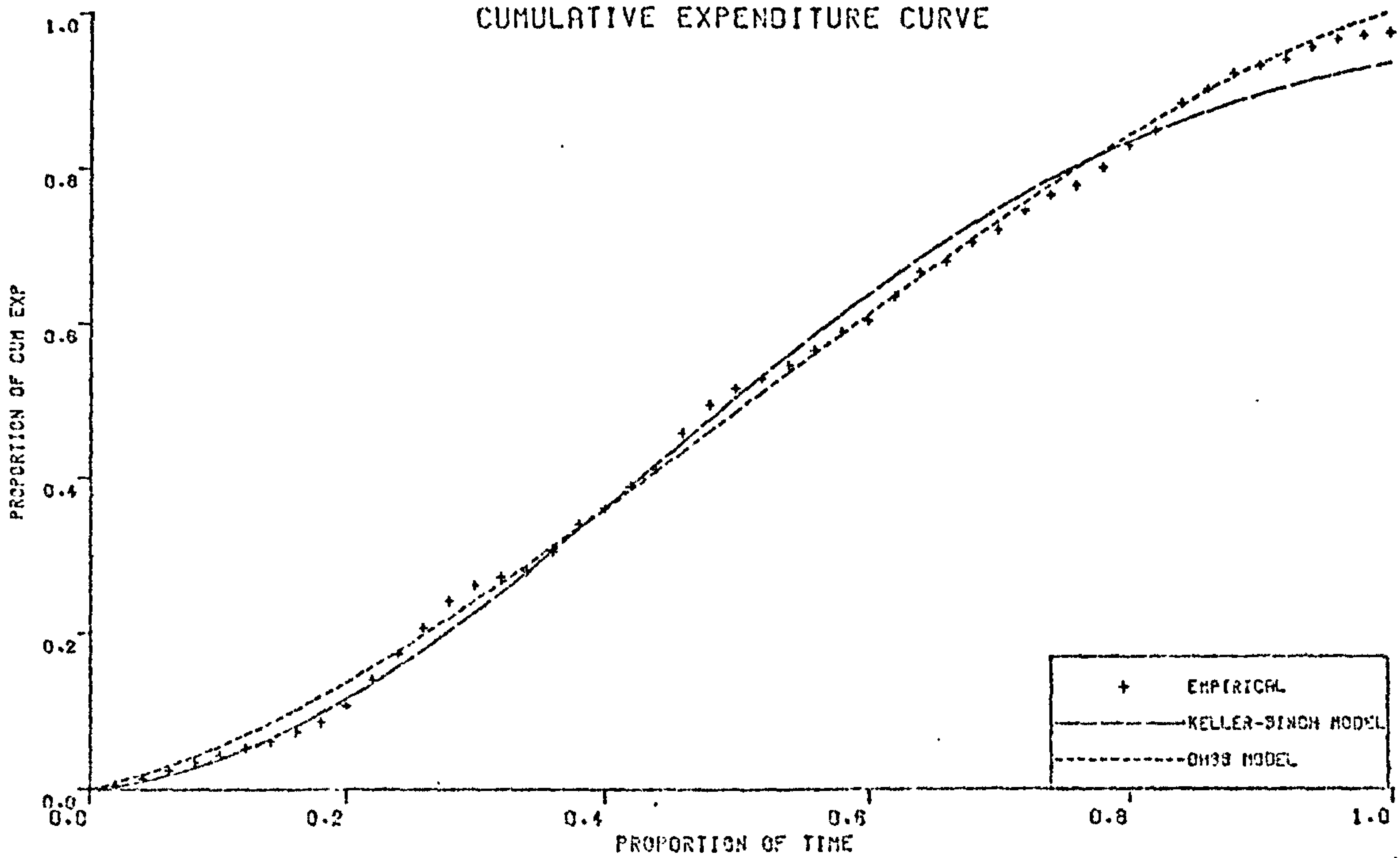


Project cost £1263027 Duration 40 months Cost category 5

Best fit parameters Keller-Singh model τ=0.55 n=1.288 Q=1.47

D.H.S.S. model C =0.475 K=10.0

Fig. 17 Empirical Data fitted to Keller-Singh & D.H.S.S. models for Project 2

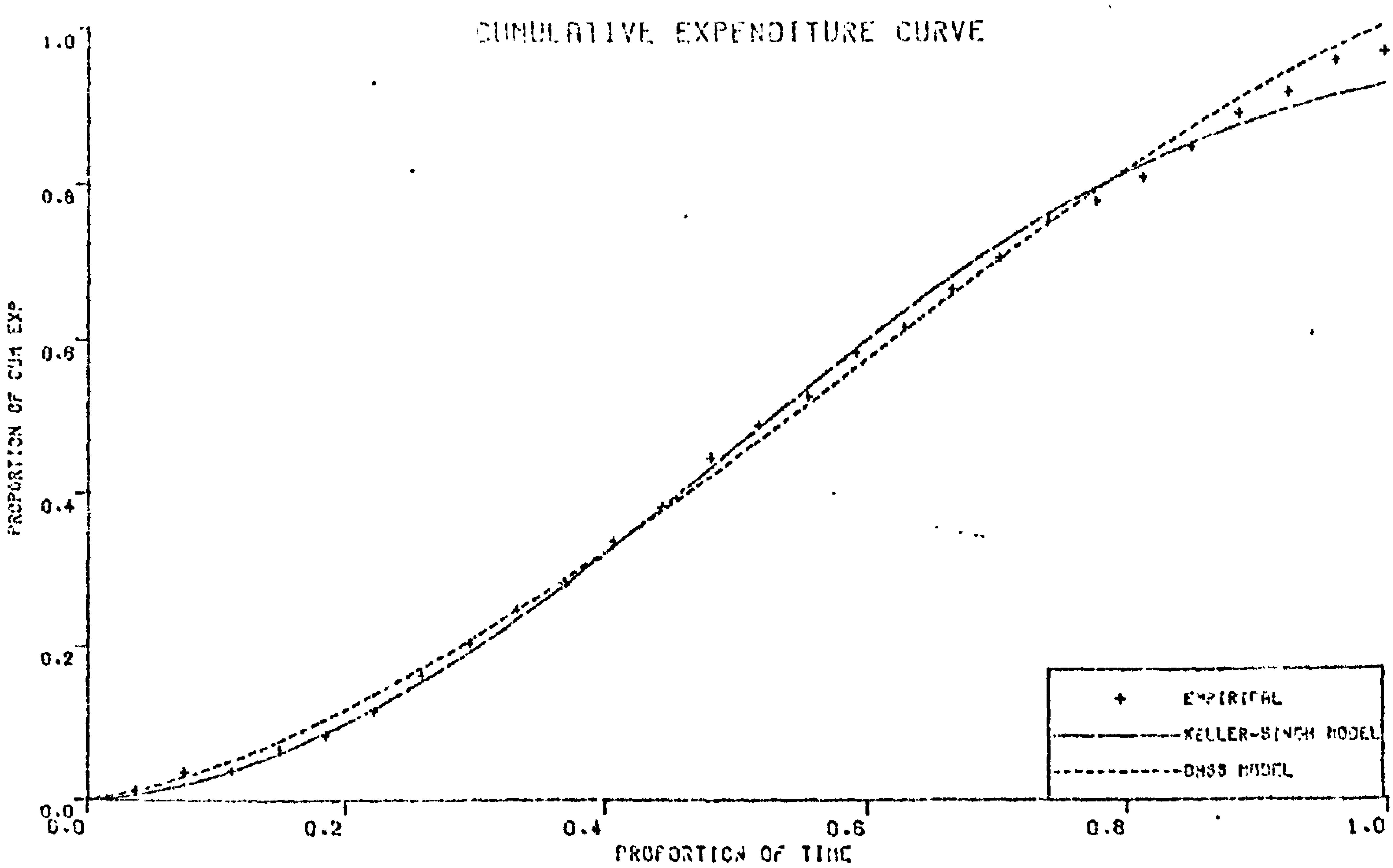


Project cost £2665833 Duration 51 months Cost category 6

Best fit parameters Keller-Singh model τ=0.563 n=1.537 O=0.784

DHSS model C=0.062 K=5.5365

Fig.4.18 Empirical Data fitted to Keller-Singh & D.H.S.S. models for Project 3

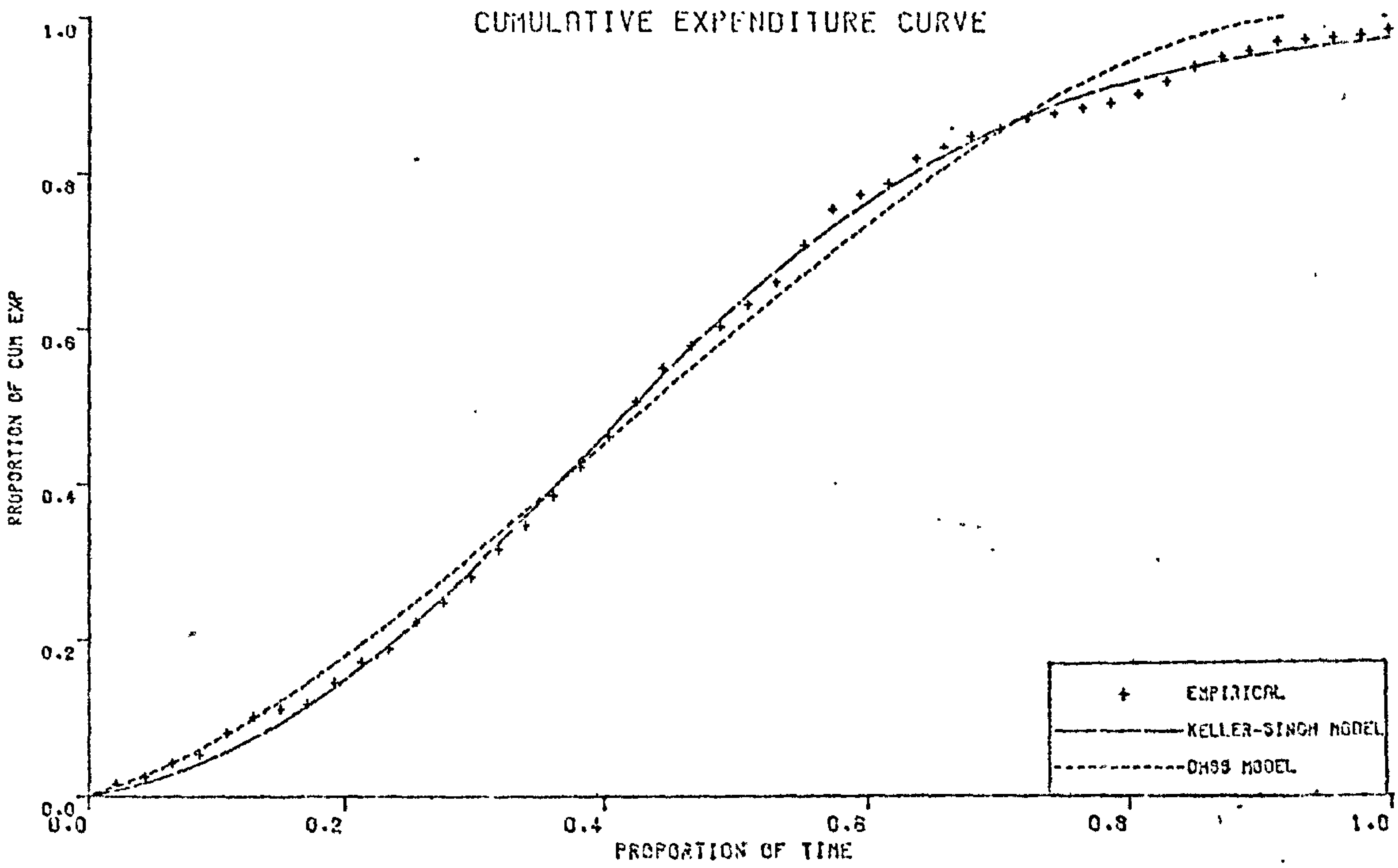


Project cost £3086697 Duration 27 months Cost category 6

Best fit parameters Keller-Singh model τ=0.5667 n=1.553 O=0.9124

DHSS model C=0.217 K=5.972

Fig.4.19 Empirical Data fitted to Keller-Singh & D.H.S.S. model for project 4

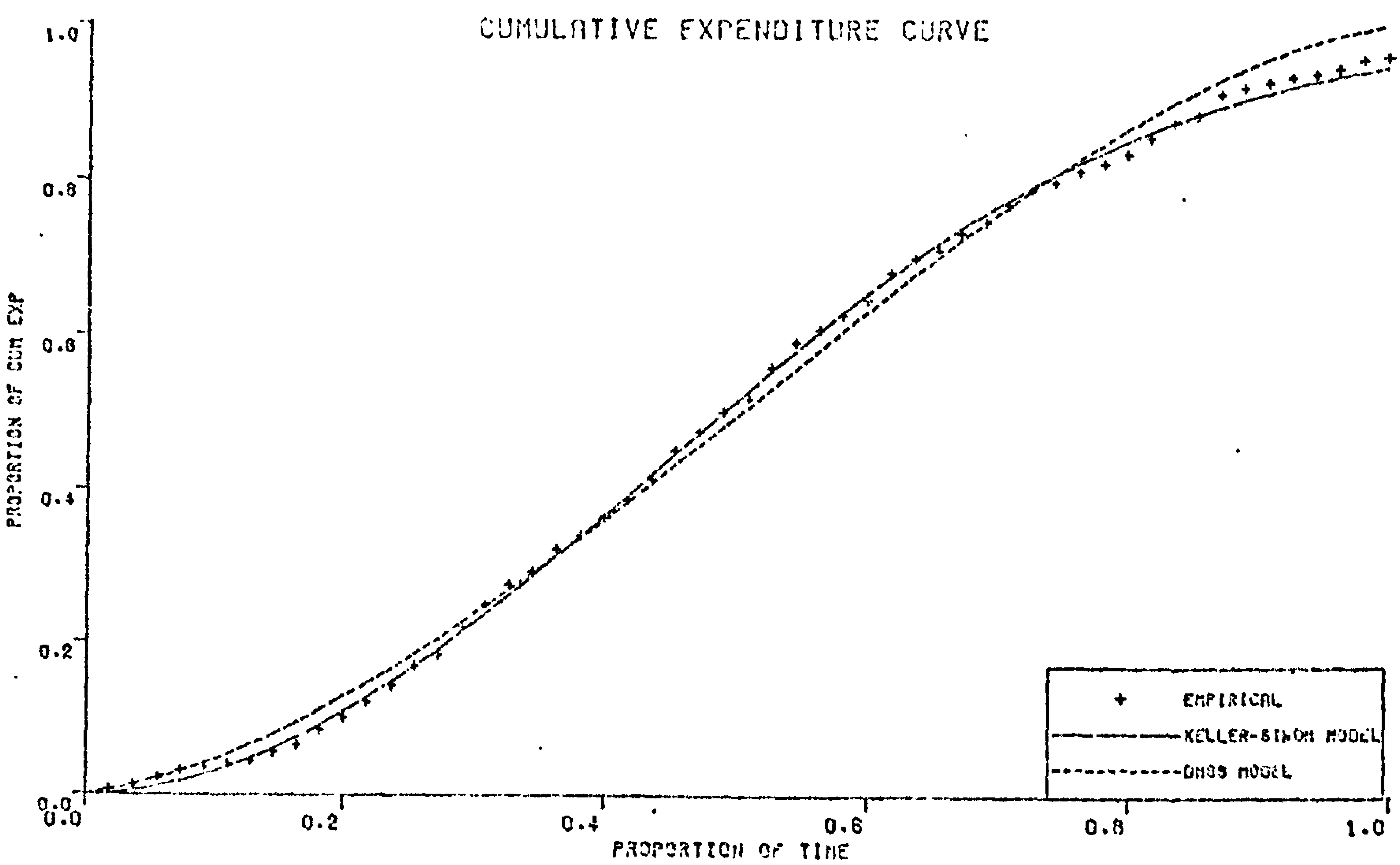


Project cost £4191139 Duration 47 months Cost category 7

Best fit parameters of Keller-Singh Model τ=0.2934 n=1.151 Q=1.6976

D.H.S.S. model C=0.383 K=3.532

Fig.4.20 Empirical data fitted to Keller-Singh model and D.H.S.S. model for project 5

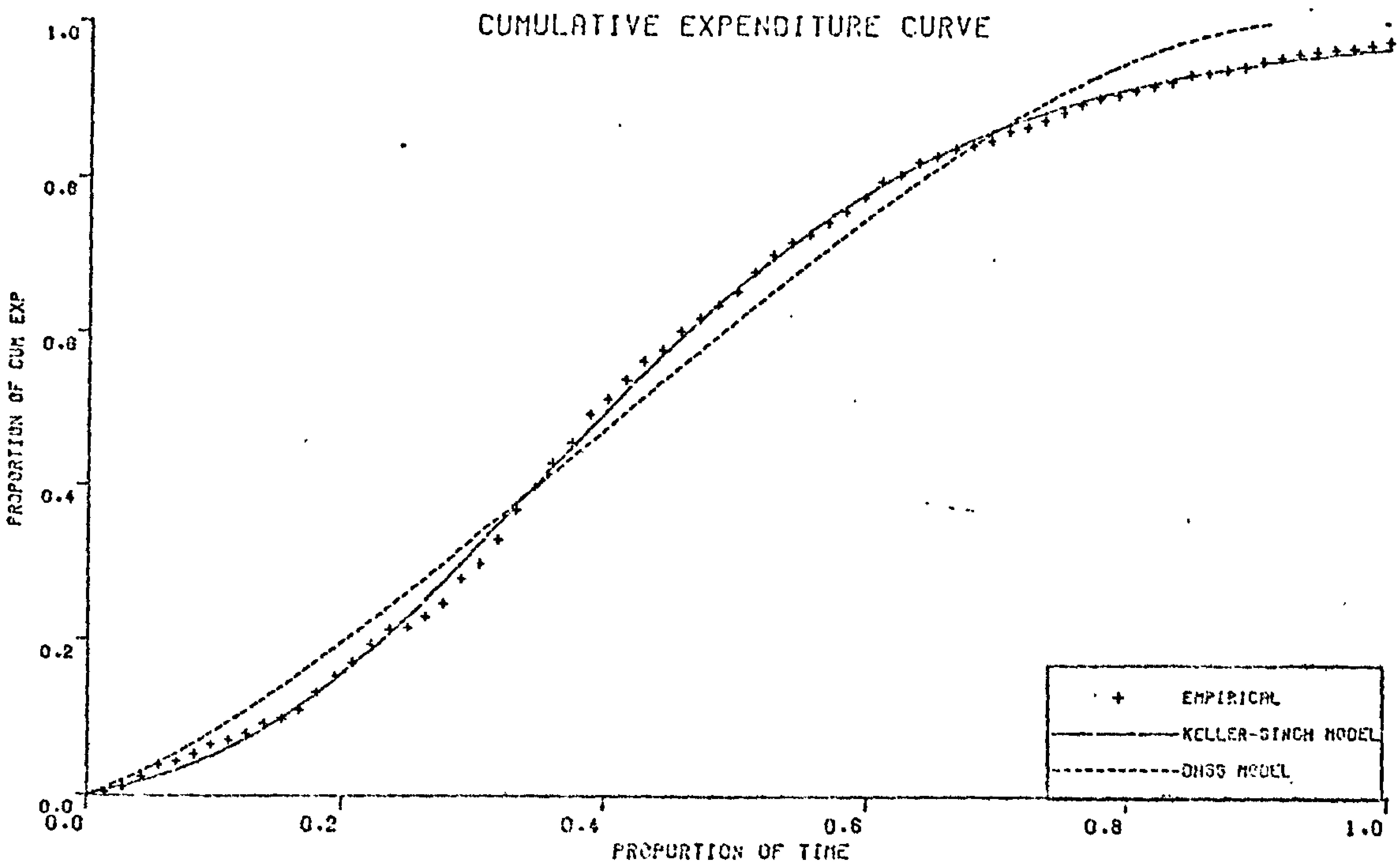


Project cost £4500000 Duration 55 months Cost category 7

Best fit parameters of Keller-Singh model τ=0.6567 n=1.8166 Q=0.4925

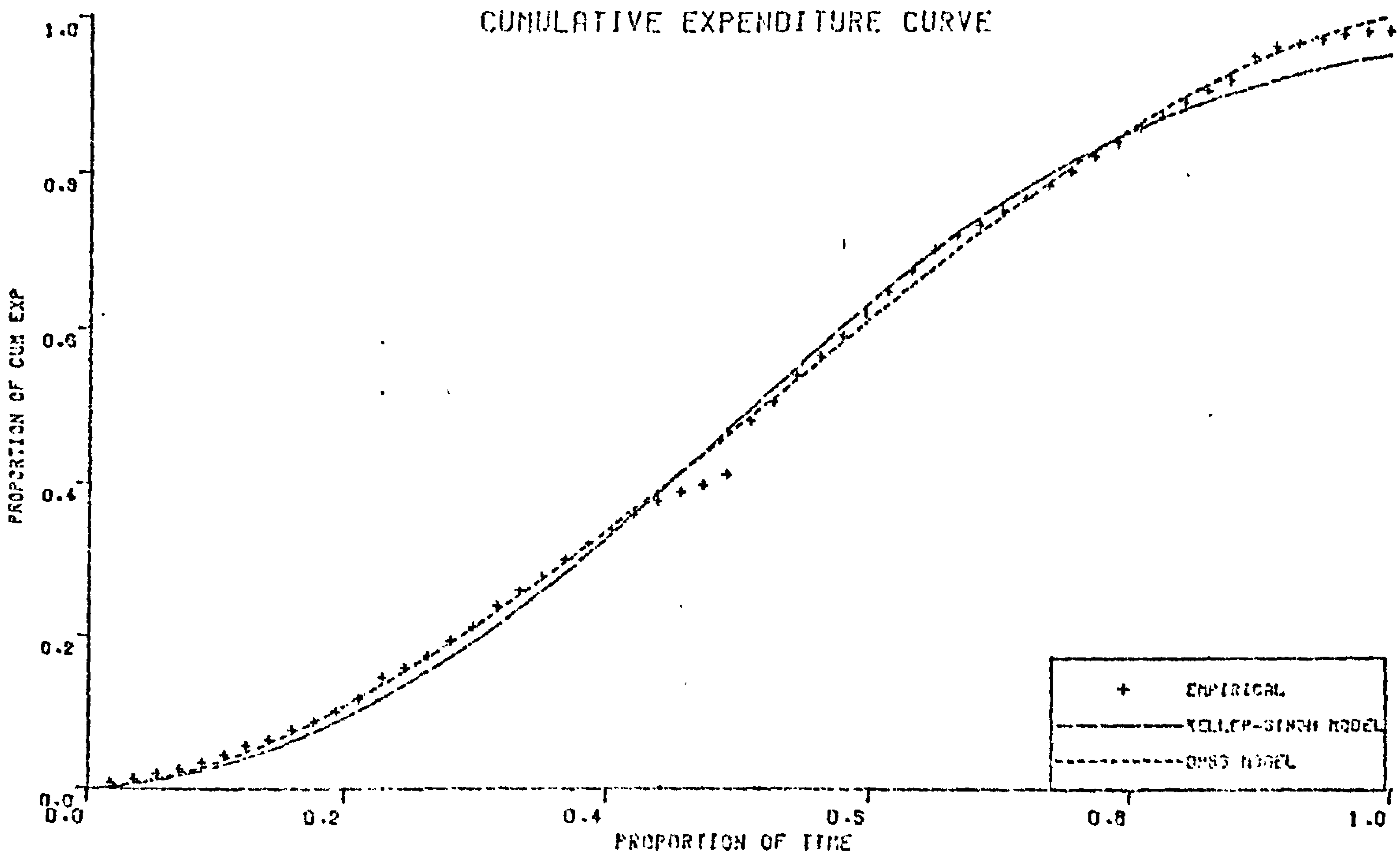
D.H.S.S. model C=0.02159 K=4.2169

Fig.4.21 Empirical data fitted to Keller-Singh model and D.H.S.S. model for project 6



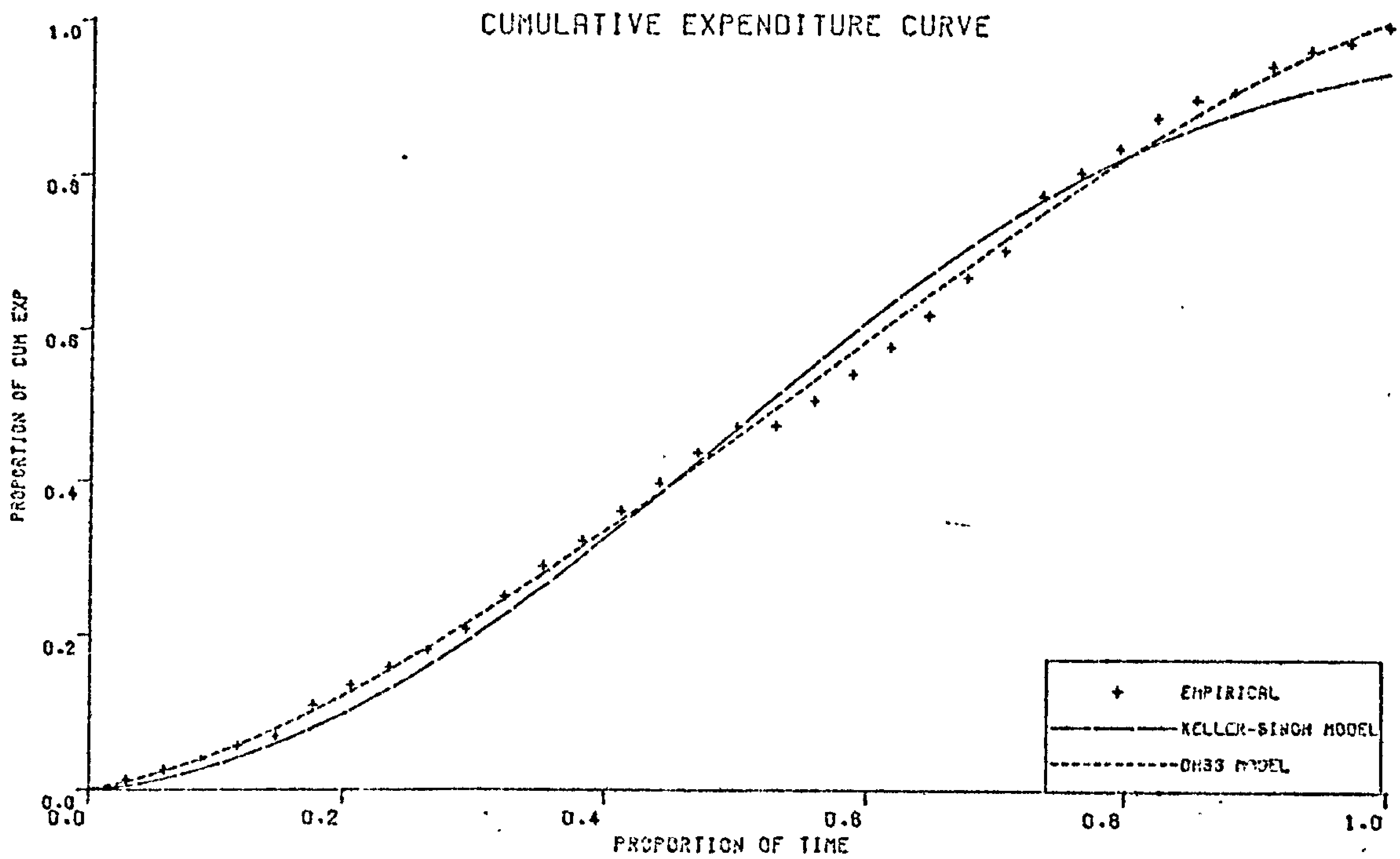
Project cost £5119406 Duration 72 months Cost category 7
Best fit parameters of Keller-Singh model τ=0.08837 n=0.7176 θ=1.27
D.H.S.S. C=0.452 K=3.793

Fig.4.22 Empirical data fitted to Keller-Singh model and D.H.S.S. model for project 7



Project cost £5873750 Duration 57 months Cost category 7
Best fit parameters of Keller Singh model τ=4908 n=1.547 θ=1.033
D.H.S.S. C=0.106 K=3.9

Fig. 4.23 Empirical data fitted to Keller-Singh model and D.H.S.S. model for project 8

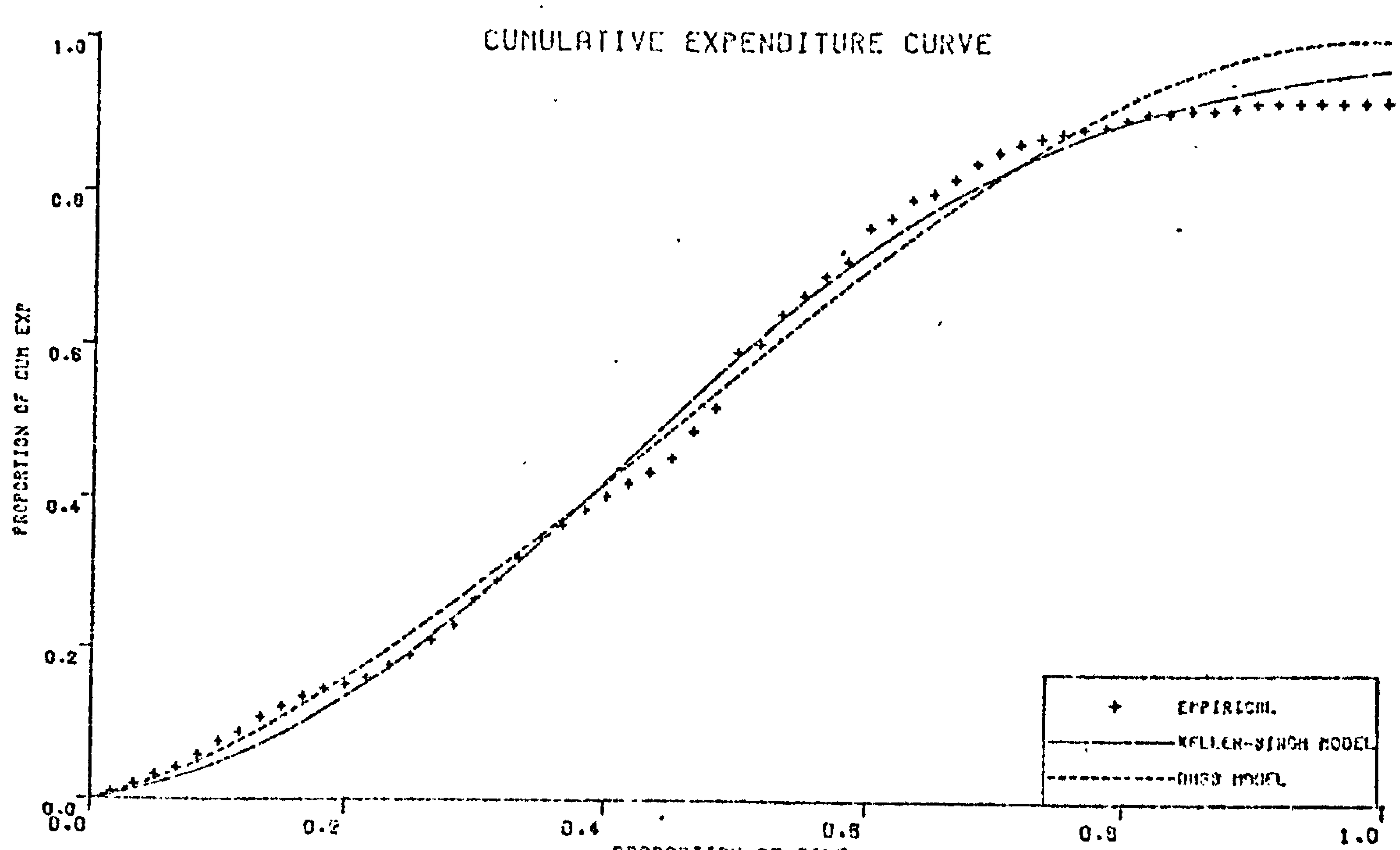


Project cost £4729605   Duration 34 months   Cost category 7

Best fit parameters of Keller-Singh model τ=0.52   n=1.50696   0=1.02187

D.H.S.S.   C=0.166   K=5.63

Fig.4.24   Empirical data fitted to Keller-Singh model and D.H.S.S. for project 9

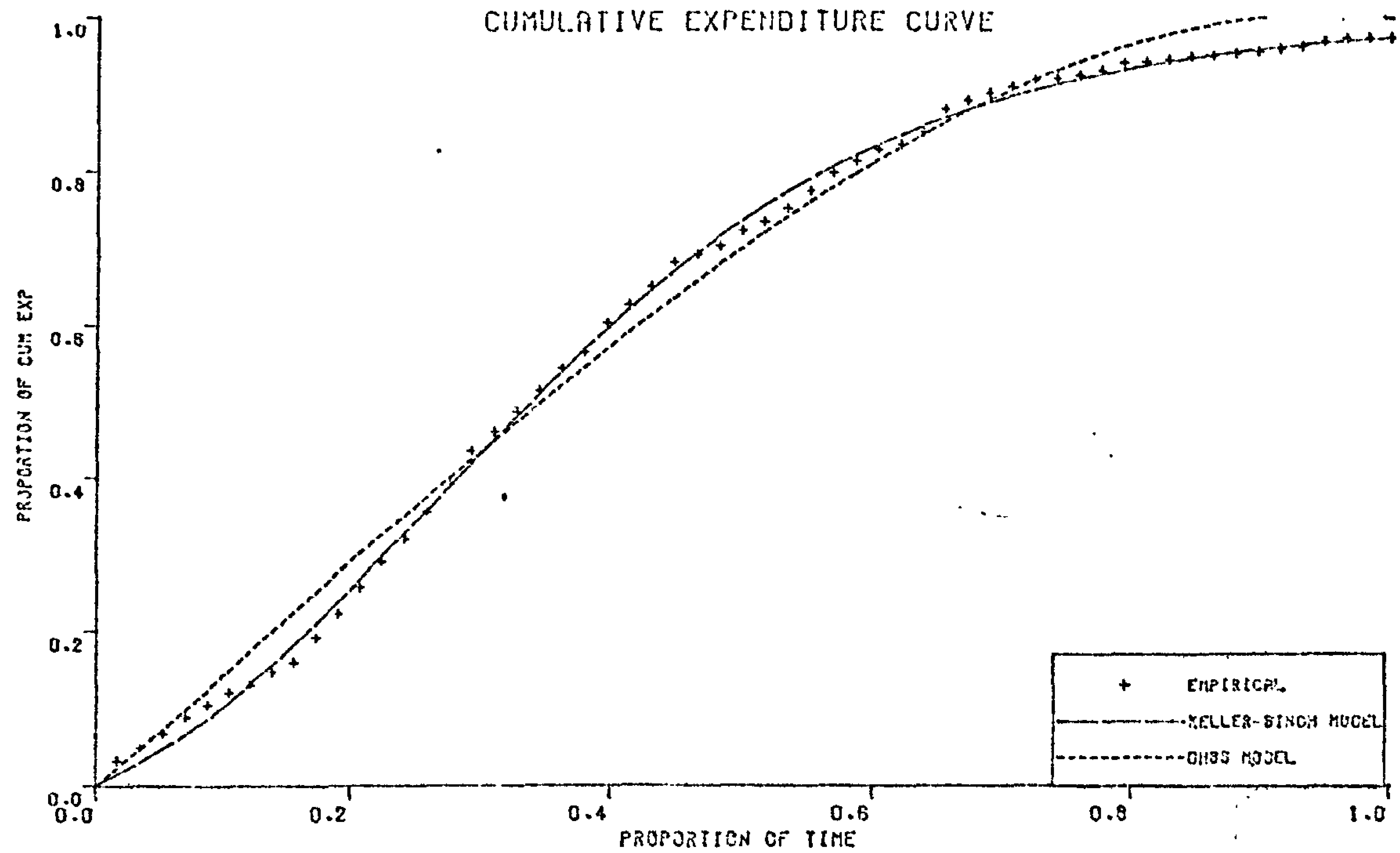


Project cost £5076133   Duration 60 months   Cost category 7

Best fit parameters of Keller-Singh model τ=0.2655   n=10627   C=2.43.

D.H.S.S.   C=0.24   K=3.63

Fig. 4.25   Empirical data fitted to Keller-Singh model and D.H.S.S. for project 10

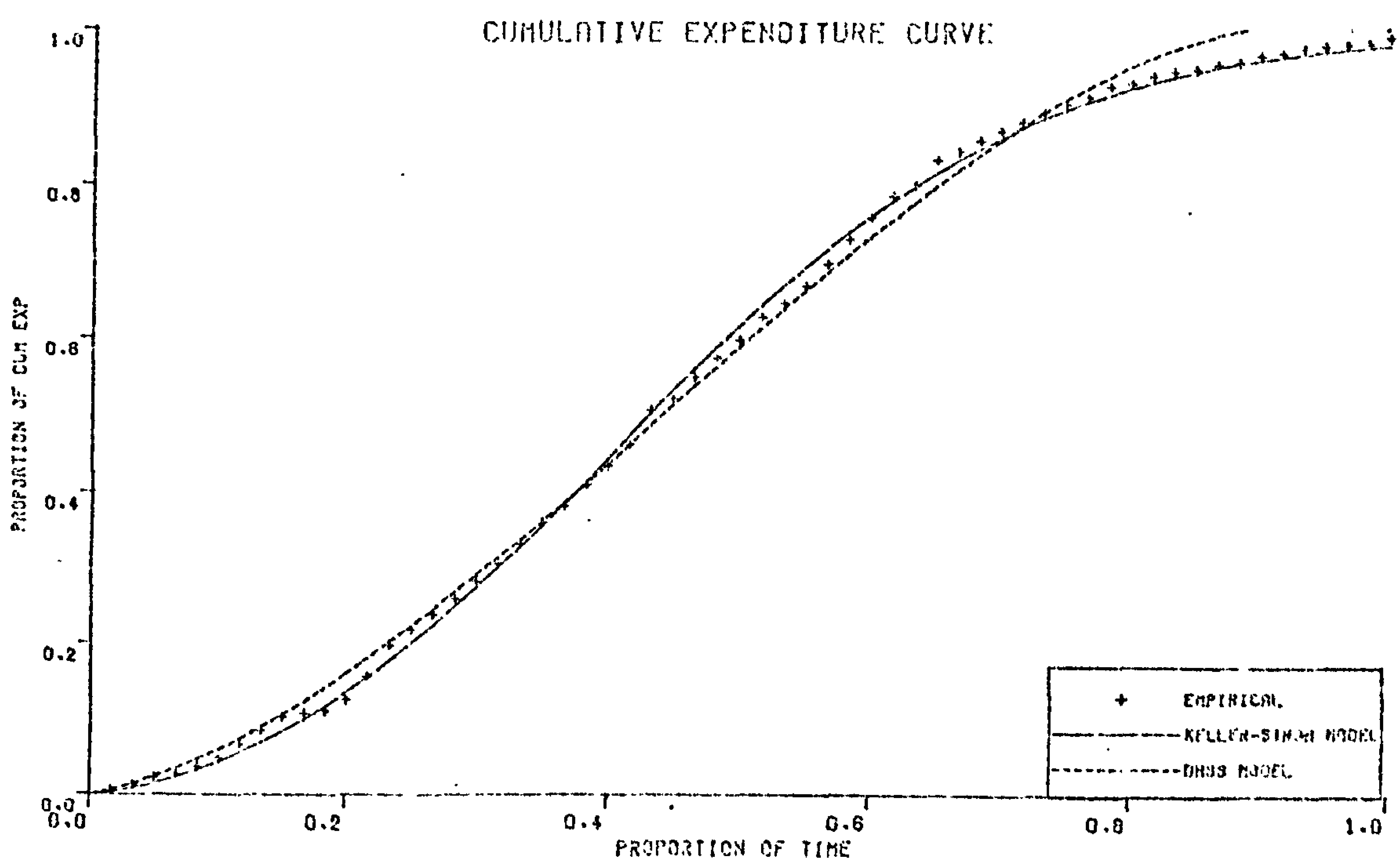


Project cost £4792240 Duration 58 months Cost category 7

Best fit parameters of Keller-Singh model τ=0.2156 n=0.9256 θ=1.679

D.H.S.S. C=0.797 K=7.718

Fig. 4.26 Empirical data fitted to Keller-Singh model and D.H.S.S. model for project 11

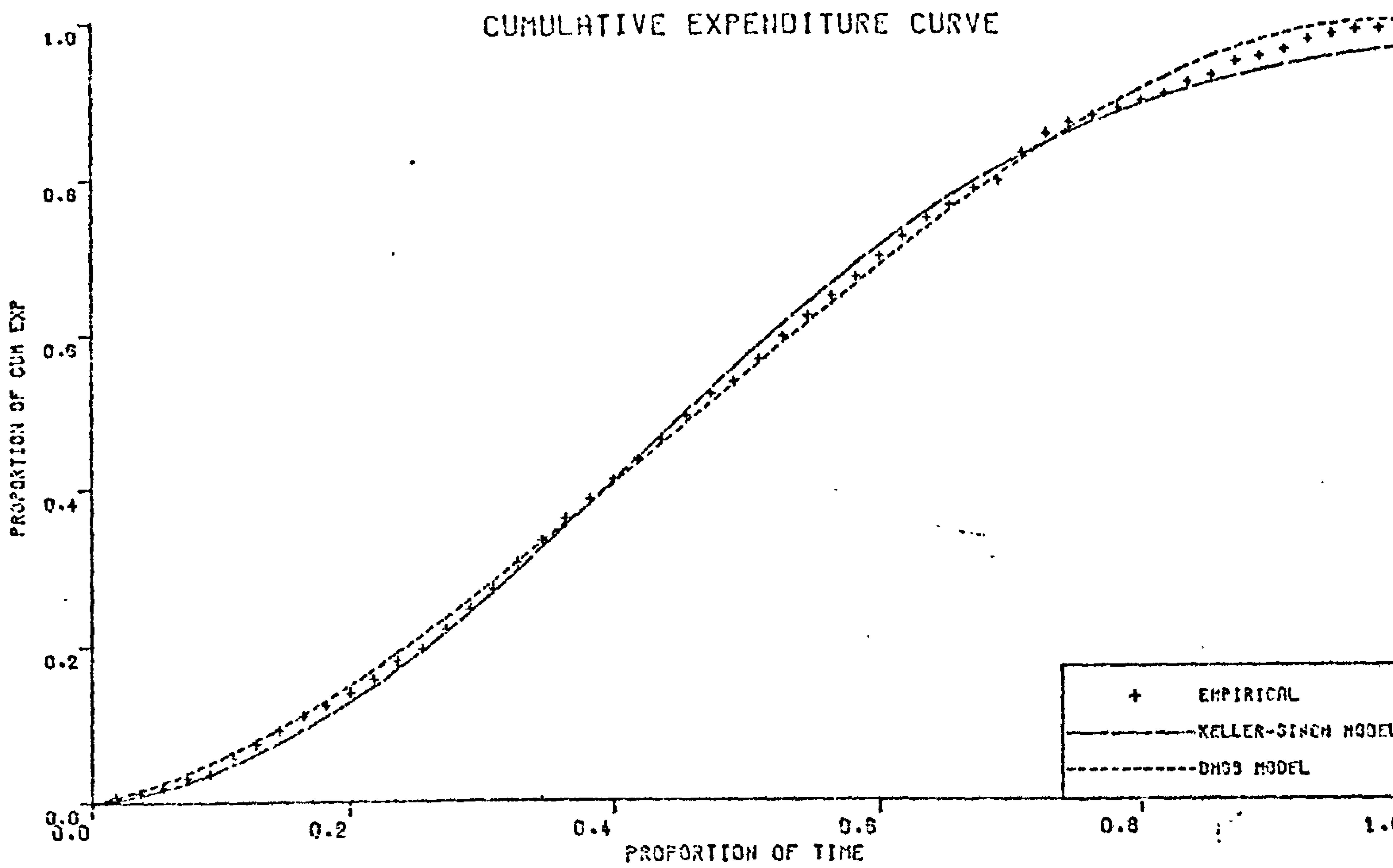


Project cost £5125000 Duration 60 months Cost category 7

Best fit parameters of Keller-Singh model τ=0.425 n=1.4987 θ=0.797

D.H.S.S. C=-0.344 K=3.013

Fig. 4.27 Empirical data fitted to Keller-Singh model and D.H.S.S. model for project 12

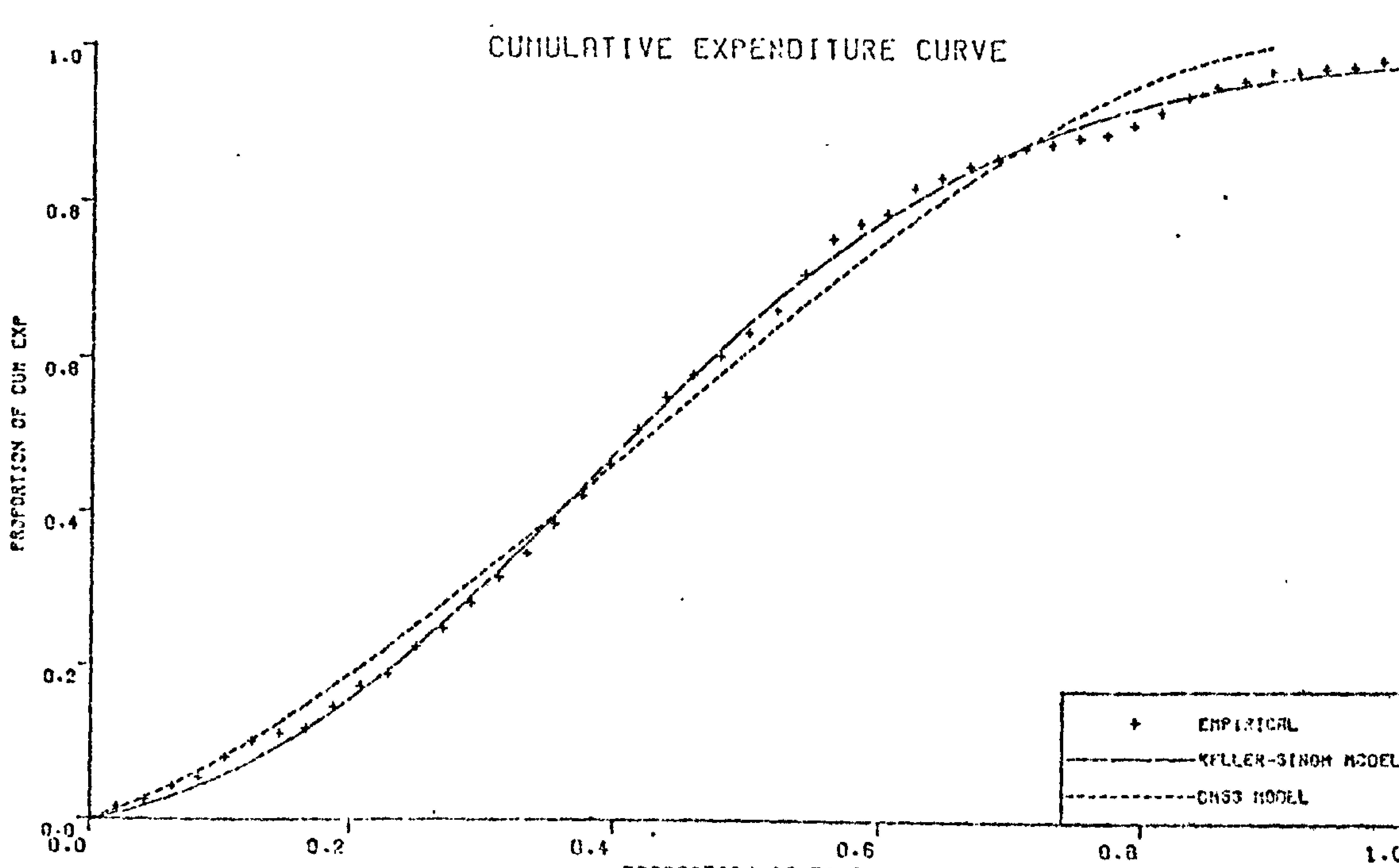


Project cost £5500000   Duration 55 months   Cost category 7

Best fit parameters of Keller-Singh model   τ=0.471   n=1.512   O=0.7925

D.H.S.S.   C=0.191   K=3.51

Fig.4.28   Empirical data fitted to Keller-Singh model and D.H.S.S. model for project 13

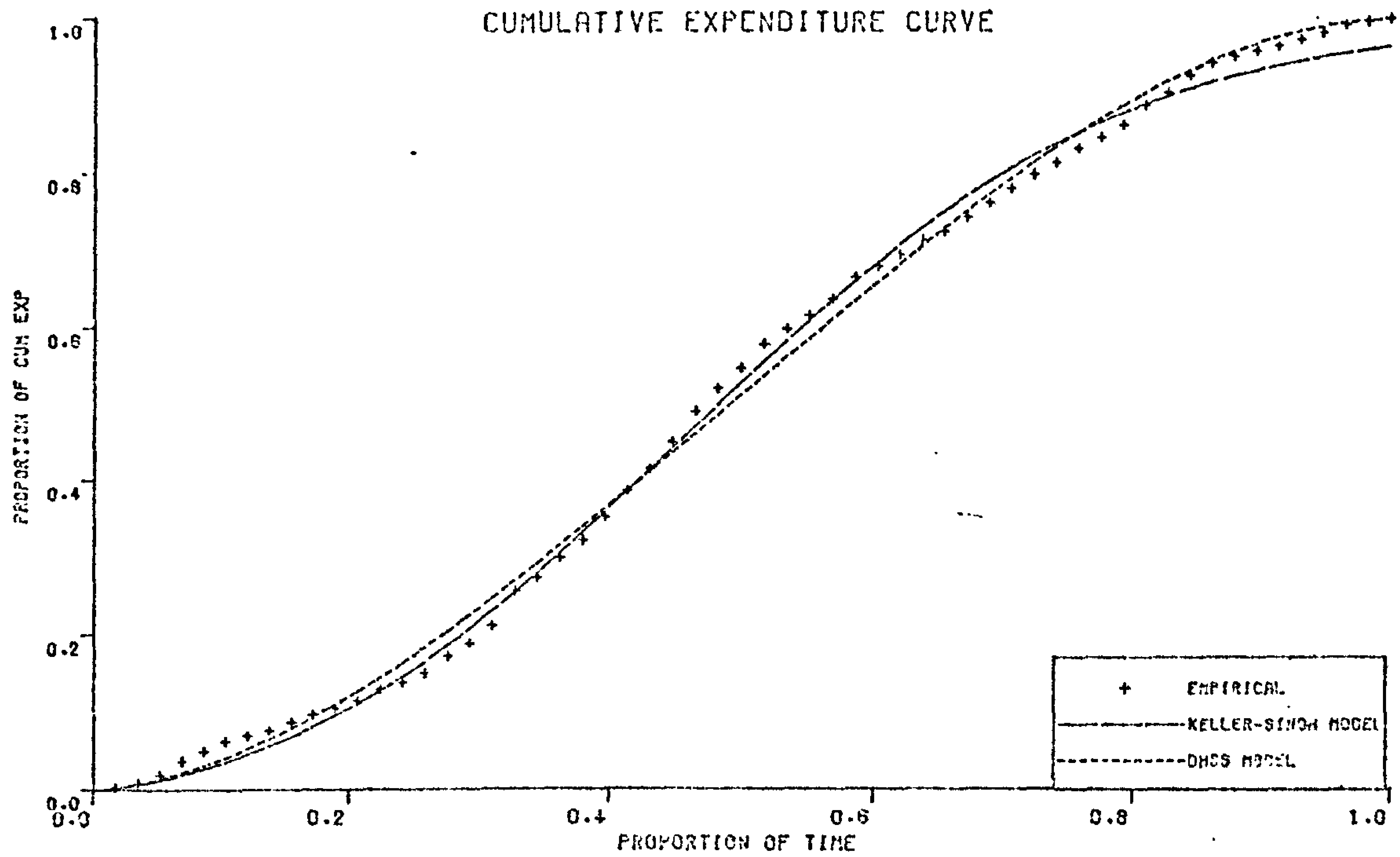


Project cost £4200000   Duration 48 months   Cost category 7

Best parameters of Keller-Singh model   τ=0.2876   n=1.149   O=1.662

D.H.S.S.   C=-0.4316   K=3.512

Fig. 4.29   Empirical data fitted to Keller-Singh model and D.H.S.S. model for project 14

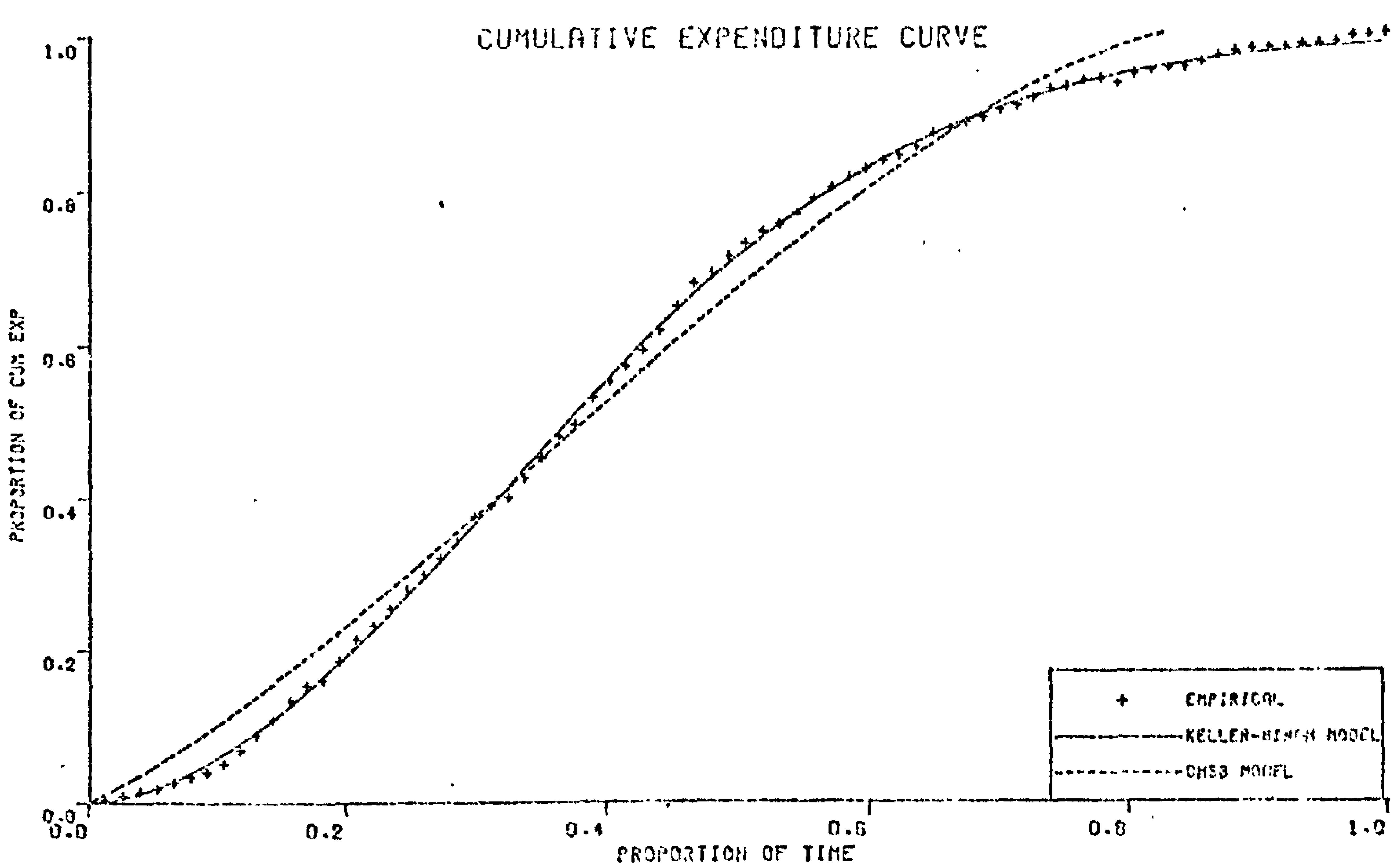


Project cost £5674563 Duration 58 months Cost category 8

Best fit parameters of Keller-Singh model τ=0.442 n=1.4817 θ=1.0689

D.H.S.S. C=-0.0429 K=3.3275

Fig.4.30 Empirical data fitted to Keller-Singh model and D.H.S.S. model for project 15

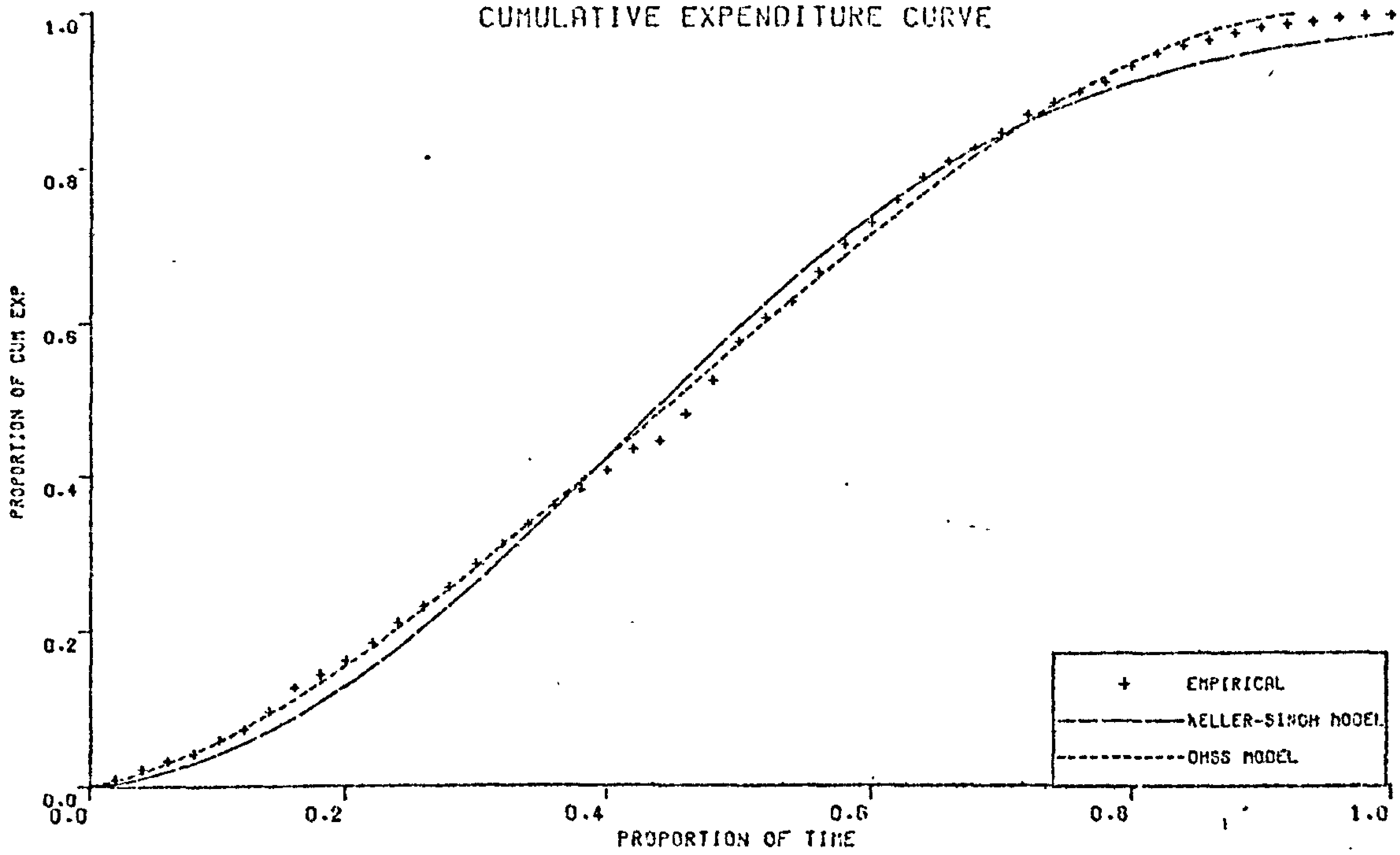


Project cost £6460369 Duration 77 months Cost category 8

Best fit parameters of Keller-Singh model τ=0.4957 n=1.6876 θ=0.3476

D.H.S.S. C=-0.6773 K=3.7065

Fig.4.31 Empirical data fitted to Keller-Singh model and D.H.S.S model for project 16

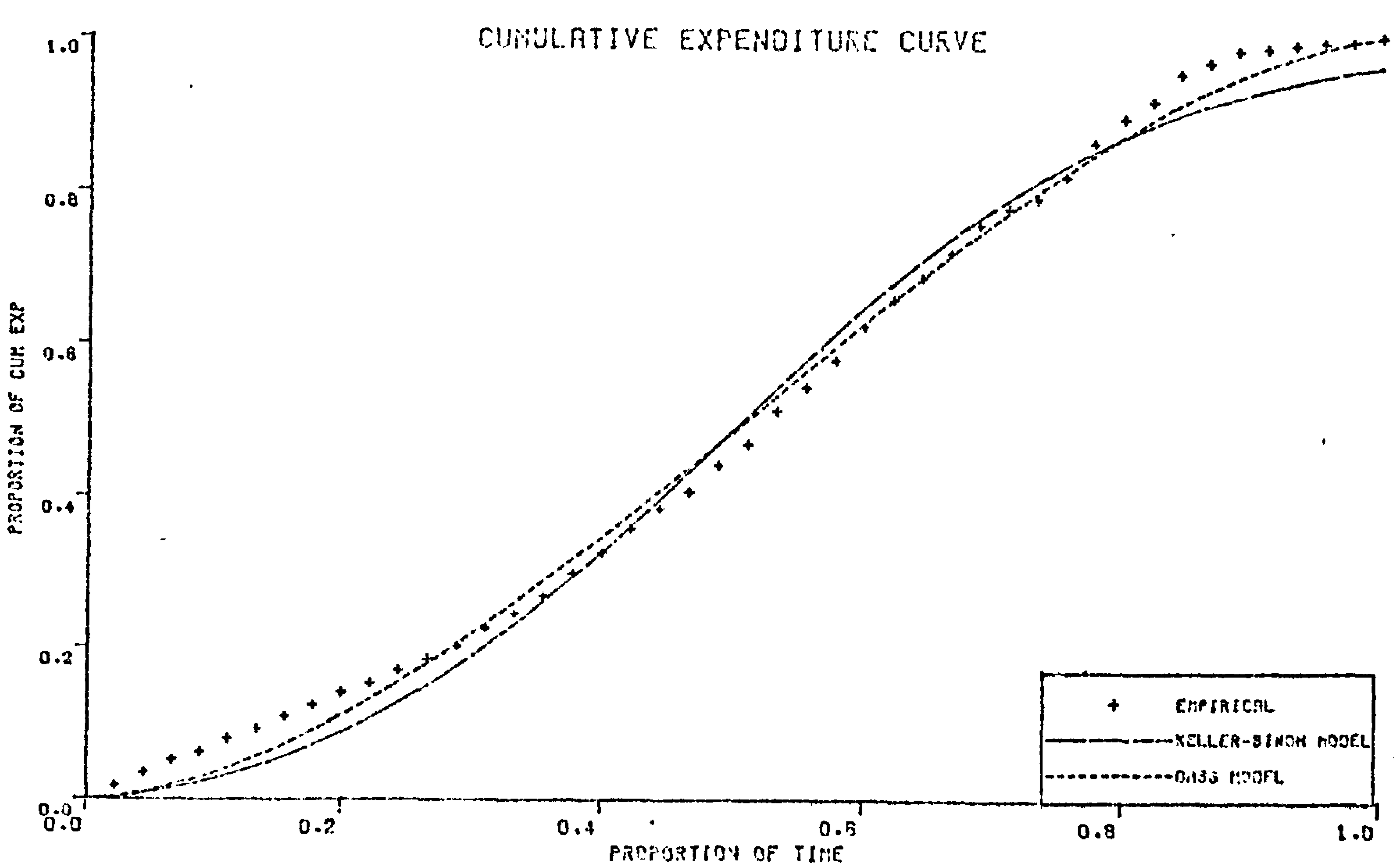


Project cost £5939380   Duration 50 months   Cost category 8

Best fit parameters of Keller-Singh model τ=0.433   n=1.482 θ=0.849

D.H.S.S.   C=-0.2823   K=3.211

Fig.4.32 Empirical data fitted to Keller-Singh model and D.H.S.S for project 17

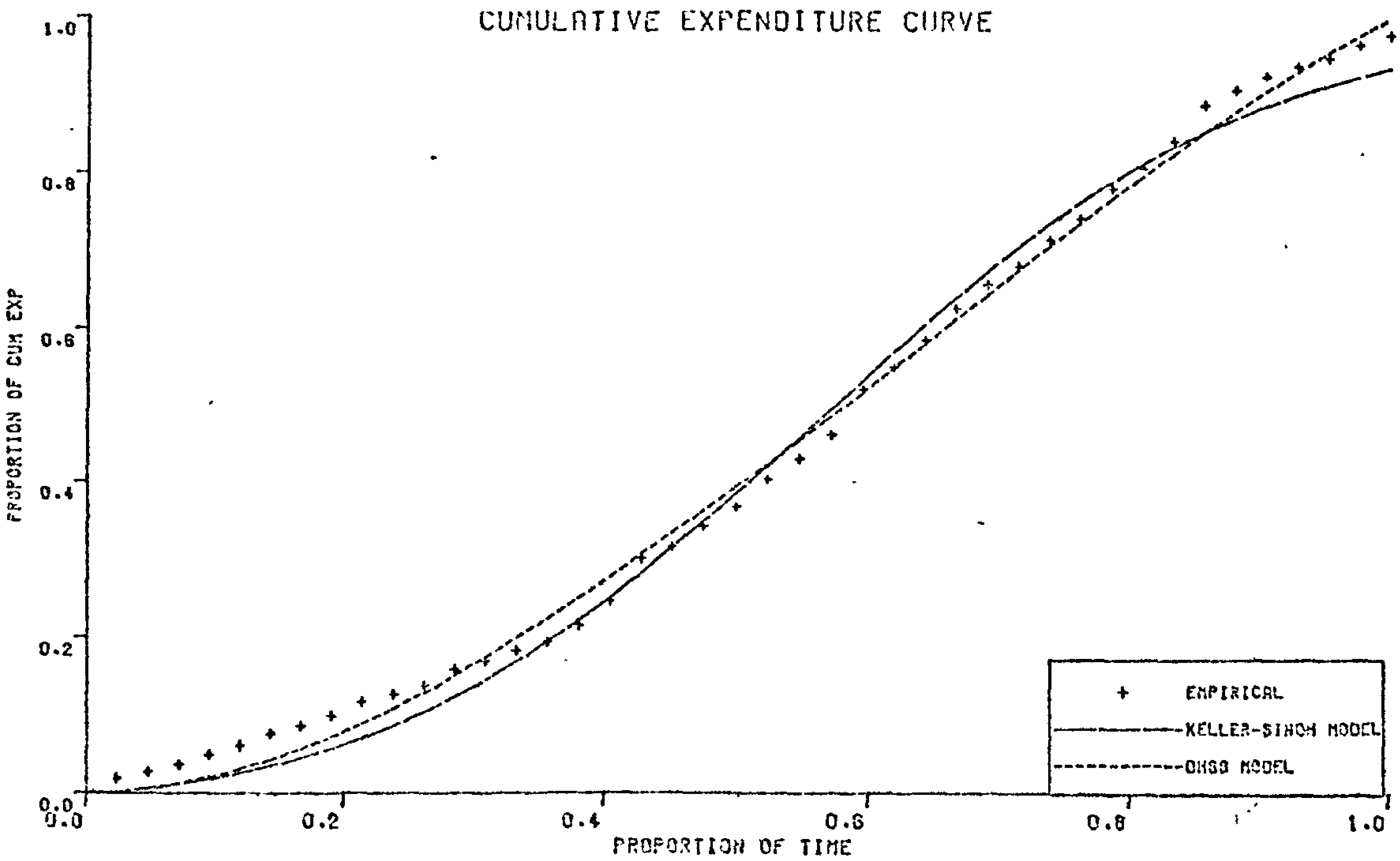


Project cost £6047500   Duration 45 months   Cost category 8

Best fit parameters of Keller-Singh model τ=0.4606   n=1.5457 θ=1.126

D.H.S.S.   C=0.06231   K=3.64

Fig. 4.33 Empirical data fitted to Keller-Singh model and D.H.S.S. model for project 18

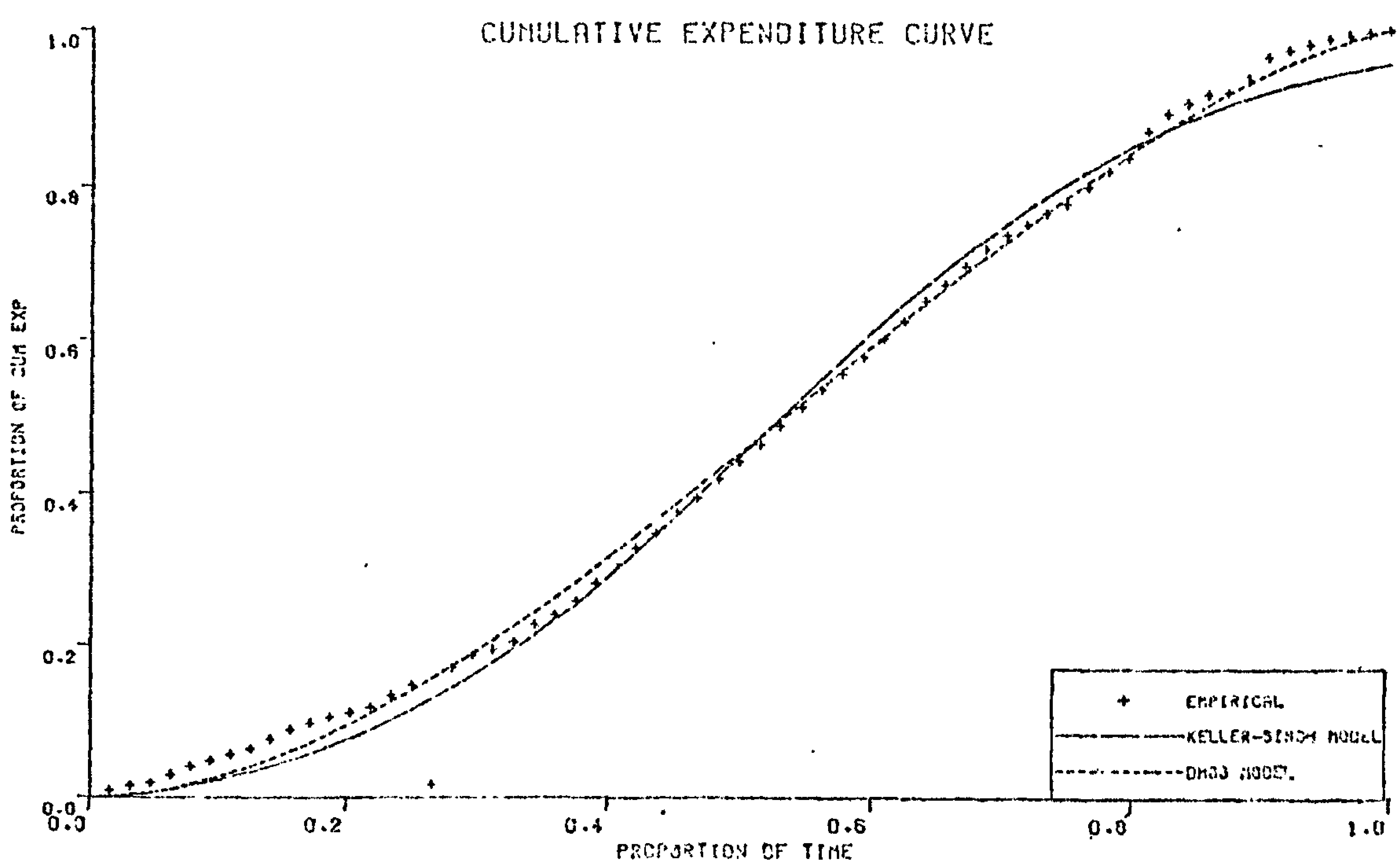


Project cost £6450000 Duration 42 months Cost category 8

Best fit parameters of Keller-Singh model τ=0.492 n=1.5785 θ=1.5

D.H.S.S. C=0.4305 K=5.565

Fig. 4.34 Empirical data fitted to Keller-Singh model and D.H.S.S. model for project 19

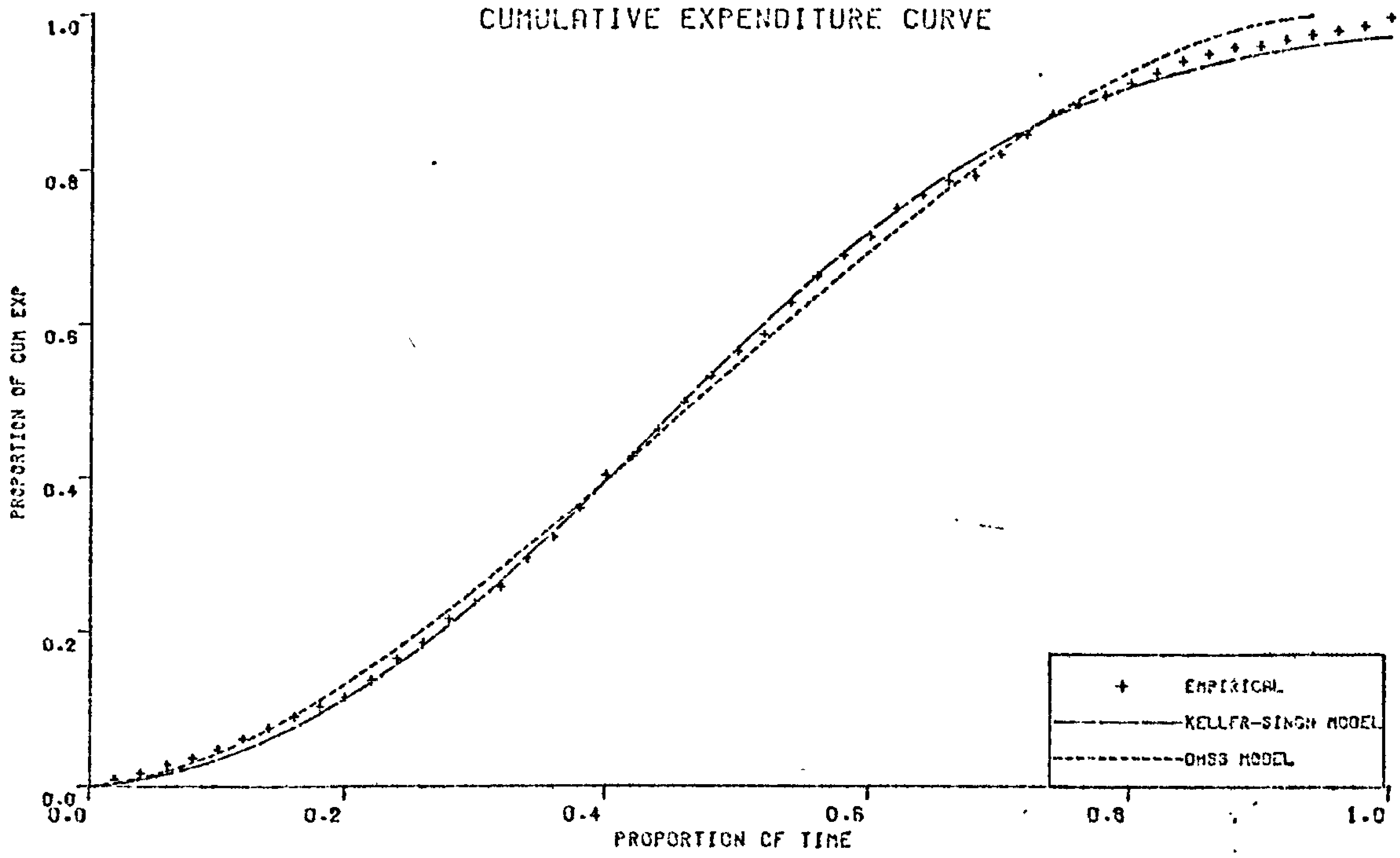


Project Cost £7100000 Duration 64 months Cost category 8

Best fit parameters of Keller-Singh model τ=0.487 n=1.6139 θ=1.154

D.H.S.S. C=0.2 K=3.915

Fig. 4.35 Empirical data fitted to Keller-Singh model and D.H.S.S model for project 20



Project cost £7100000 Duration 50 months Cost category

Best fit parameters of Keller-Singh τ=0.4337 n=1.5186 θ=0.92399

D.H.S.S C=-0.184 K=2.956

Fig. 4.36 Empirical data fitted to Keller-Singh model and D.H.S.S. model for project 21

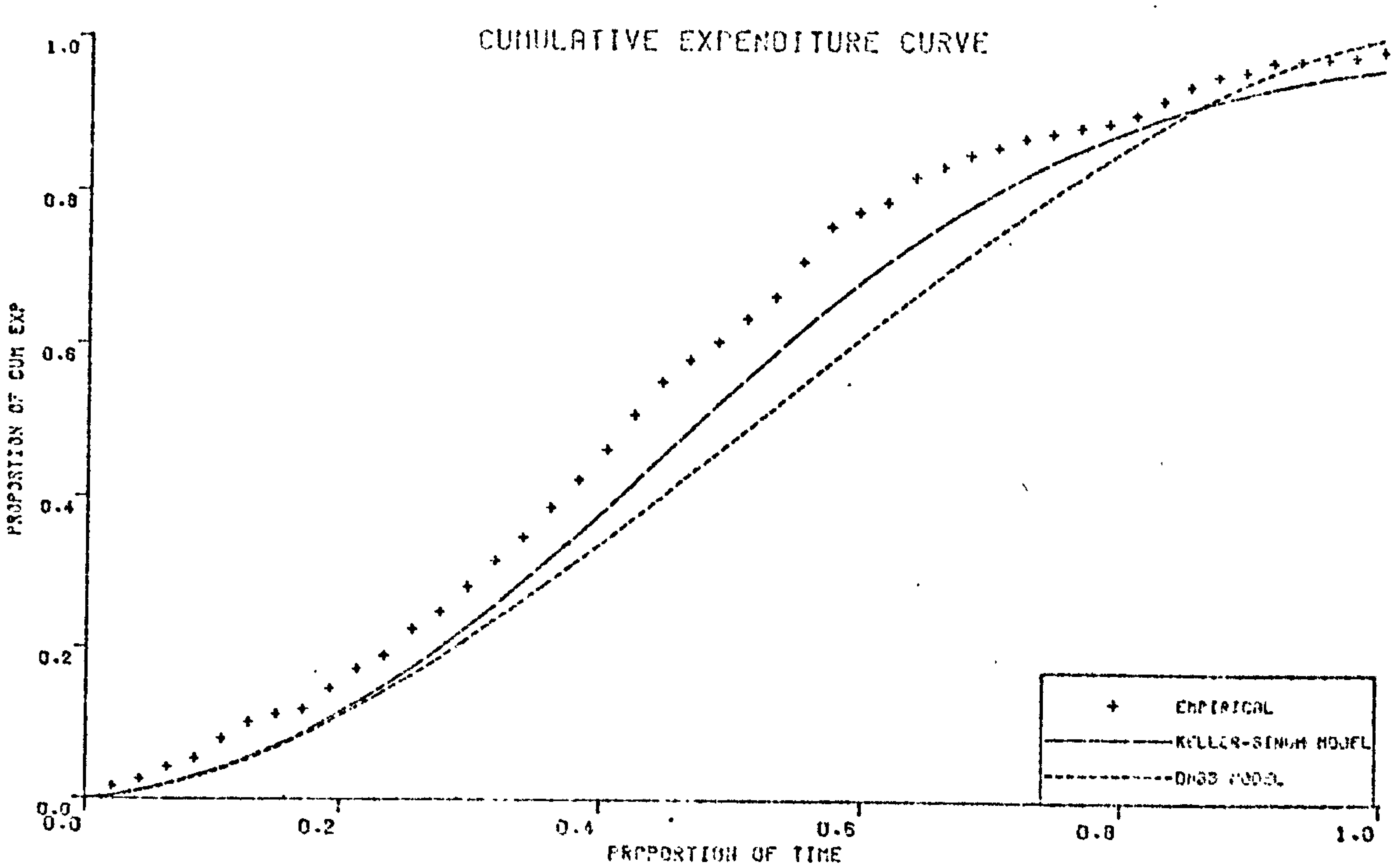


Fig. 4.37 Forecasts from Keller-Singh & D.H.S.S. models using standard set of parameters for cost category 7 and compared with actual data for project 6, of the same cost category

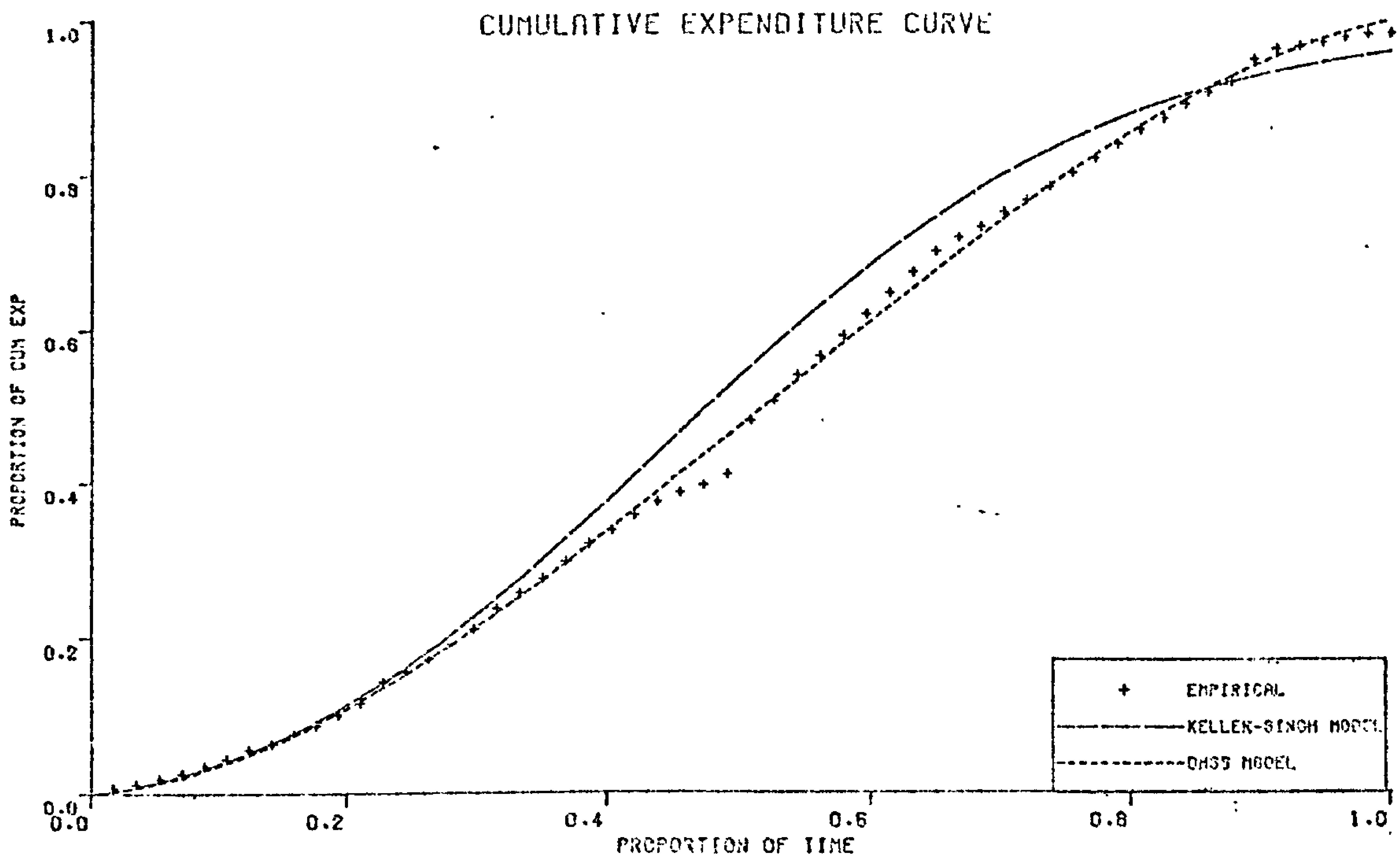


Fig. 4. 38 Forecasts from Keller-Singh & D.H.S.S. models using standard set of parameters for cost-category 7 and compared with actual data for project 9, of the same cost-category.

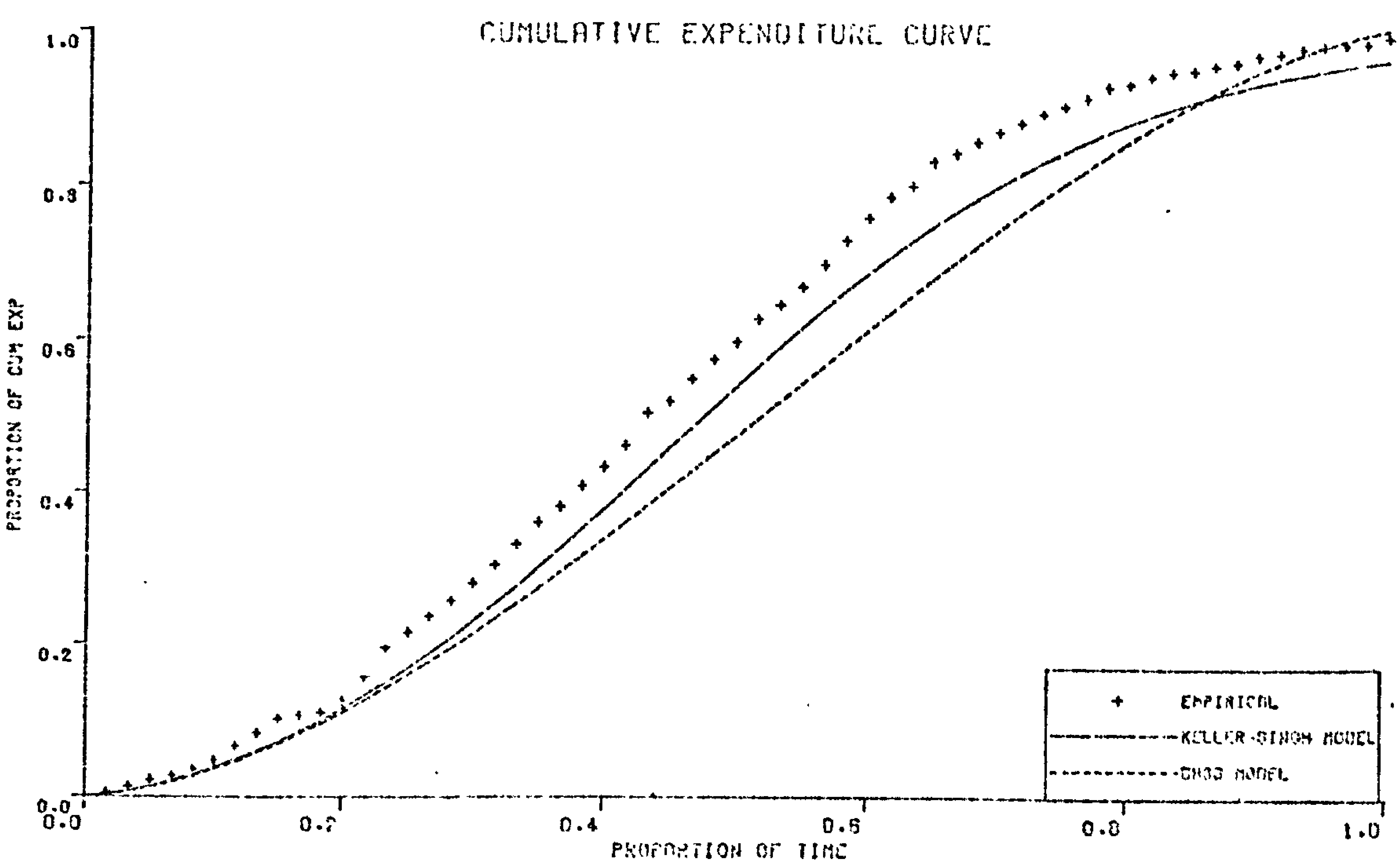


Fig.4.39 Forecasts from Keller-Singh & D.H.S.S. models using standard set of parameters for cost-category 7 and compared with actual data for project 13, of the same cost-category.

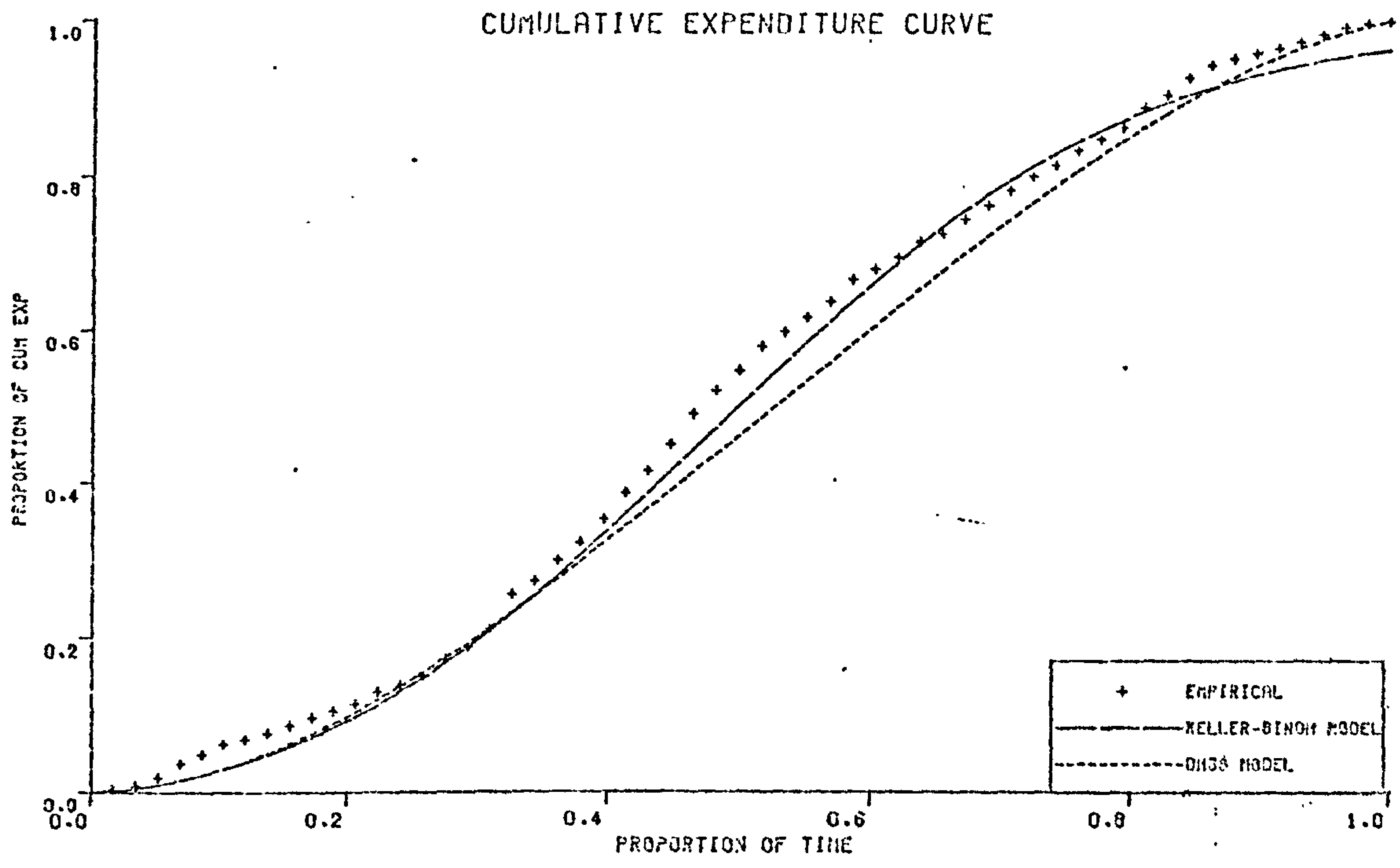


Fig. 4.40 Forecasts from Keller-Singh & D.H.S.S. models using standard set of parameters for cost-category 8 and compared with actual data for project 16, of the same cost-category.

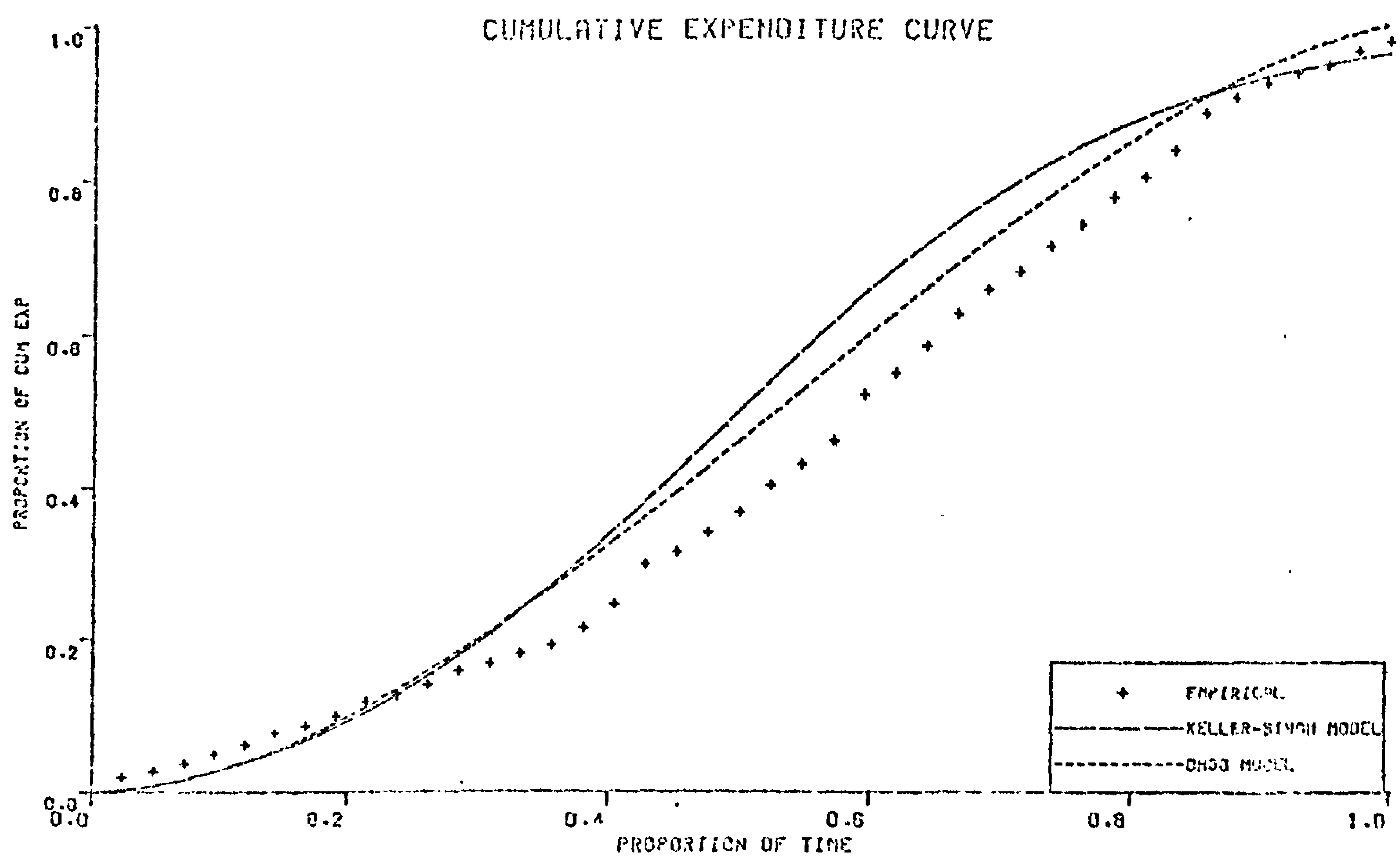


Fig. 4.41 Forecasts from Keller-Singh & D.H.S.S. models using st[illegible]lard set of parameters for cost-category 8 and compared with actual data for project 20 of the same cost-category.

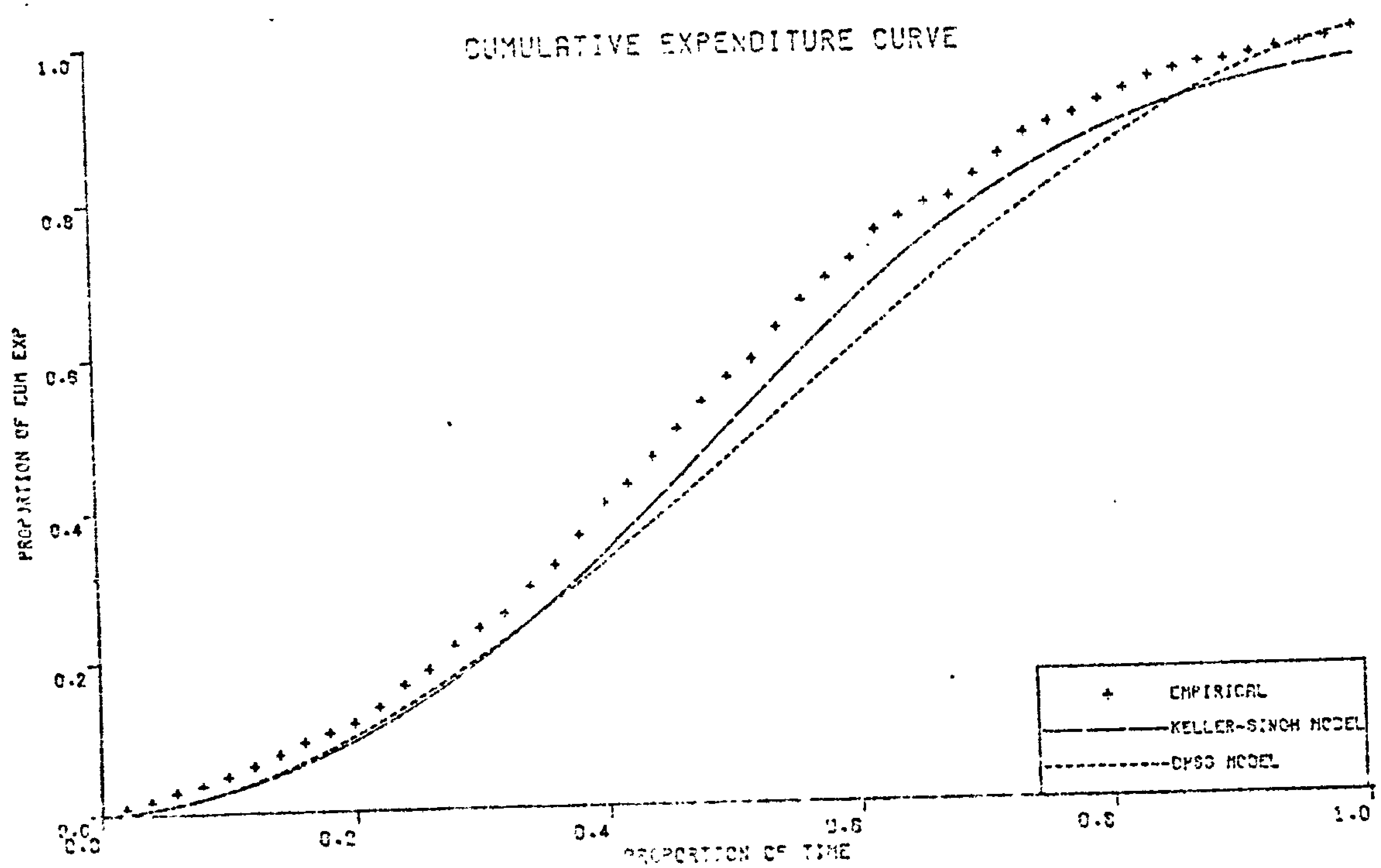


Fig. 4.42 Forecasts from Keller-Singh & D.H.S.S. models using standard set of parameters for cost-category 8 and compared with actual data for project 23 of the same cost-category.

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4.2.6 Conclusions

1. Out of 21 of the projects for whom expenditure data were analysed, the Keller-Singh model provided the better fit for 11 projects, whilst the D.H.S.S. model provided tha better fit for the other 10 projects. Accordingly both methods are of comparable accuracy for fitting actual expenditure data.

2. To check the validity and accuracy of prediction for the two models, forecasts were made for a given set of standard parameters for the projects of different cost categories. These forecasts were compared with the actual values of project expenditure for a typical project of the same cost category.

Figures 4.37-4.42 show that forecasts using the Keller-Singh model are generally better than those predicted by the D.H.S.S model. However, the D.H.S.S. model is generally simpler to use in practice than the Keller-Singh model.

A study of both the models and the characteristics of their parameters show that:

1. The range of the values for the Keller-Singh model for the project expenditure data analysed is smaller than those for the D.H.S.S. model. Table 4.14 gives the minimum and maximum range for each parameter for the two models. It is this smaller range that enables the Keller-Singh model to forecast expenditure with more confidence for similar new projects.

2. The parameters of the Keller-Singh model are capable of physical interpretation and have a higher degree of flexibility due to the increased number of parameters in model as compared

with the D.H.S.S. model.

3. With the D.H.S.S. model depending upon the values of the parameters used one can occasionally obtain a negative expenditure which cannot be meaningfully interpretated, whereas the Keller-Singh model is always a non-decreasing function.

4. Using normalizing constants the Keller-Singh model can be transformed into a suitable distribution whereas it is not readily done with the D.H.S.S. model.

4.3 General conclusions of the chapter

In this chapter a method for representing expenditure or effort and the rate of expenditure or effort as a function of time originally proposed by Keller-Singh is described.

Historical cost data can be used to provide a guide for estimating the build-up of activity and costs during the course of a project. The method has been developed and used over the years as a supporting tool for management in relation to planning and control of project expenditure/efforts. It gives an early warning as to the way in which a project is going, and in particular whether it is likely to meet its prime targets in relation to cost and time. The model can be used for

Initial budget expenditure forecasting.

Budget control, for the preparation of tender for large projects, maximising C.P.A. claims, quantifying risk, manpower planning and for various other purposes. For illustration purposes practical examples of some of its uses has been described.

Expenditure data for a large number of D.H.S.S. projects was analysed, and model was fitted to the data. A comparison was made between Keller-Singh and D.H.S.S. expenditure forecasting models. Both the models were fitted to the data. Both models fitted well to the expenditure data. A set of standard parameters for both models was obtained. Forecasts were made from both models and compared with actual data for projects.

Both the models are of comparable accuracy for fitting actual expenditure data. However, forecasts from the Keller-Singh model are generally better than D.H.S.S. model.

Compared with the cost control techniques currently in use the proposed technique should provide both clients and contractors with a means of more closely and effectively planning and controlling costs on a project. The model can be used in conjunction with CPM/PERT network as described earlier (Singh, 1978).

CHAPTER 5

PROBABILISTIC ANALYSIS OF COMPLETION TIME OF A HOUSING PROJECT

In this chapter quantification aspects of risk involved with the completion time of a project are studied. A number of statistical distributions are fitted for this purpose to the ratio of actual and programmed duration for the different activities of a housing project. A brief introduction to these distributions and the various methods for the estimation of parameters of a distribution is provided. Chi-squared and Kolmogorov-Smirnov tests for the goodness-of-fit are considered.

5.1 Introduction

As discussed in chapter two much work has been carried out on planning techniques (network planning in particular) and associated fields in the past two decades. However, there is little information available on the practical use of "feed-back" data to re-assess and calculate reasonably accurate activity durations for a housing project. According to Stoneman (1979) "This is probably due to problems in anticipating, recognising, quantifying, and then making the appropriate due allowances for the considerable variations in actual value (and distributions) of outputs and activity durations achieved due to such diverse factors as site conditions, delays, different contractors organisations and working methods/procedures etc. Nevertheless, accurate and reliable activity durations would seem to be the essence of effective programming in practice".

5.1.1 Historical Perspective

A number of texts refer to activity durations and their estimation - particularly through the use of PERT - "Three time" estimates. Adrian (1973), Pilcher (1976) and Lockyer (1965) have demonstrated the use of activity duration calculation by PERT. Recent work in this area has been extended to consider the effects on the contract duration, costs and expenditure curve of the combination of critical activities with differing assumed duration distributions. Van Slyke (1963) has used Monte-Carlo simulation to solve PERT network taking various probabilistic distributions for activity times and showing their effect on the project duration and comparing these results with conventional PERT results.

Charnes et al (1964) have made an attempt to introduce the exact distribution of probabilistic activity durations to derive the precise distribution of project completion times. Martin (1965) carried out the pioneering analytical work to find completion time distribution of directed acyclic network. Burt & Garman (1971) have suggested a cumulative distribution function for stochastic network durations. Sehgal (1978) has considered effects of network structure and activity time distributions on completion time distributions and final cost. Singh (1978) has focussed on the application of risk analysis to planning and the effects of derived expenditure/time curves for activities on the properties of project durations, costs and expenditure curves.

Baldwin et al (1971) carried out research into the causes of delay in the construction industry. Their research is based on the questionnaires sent to contractors, architects and engineers in all the states of the U.S.A. It was found that one of the main reasons for programmed work not being completed on time was the ineffectiveness, or inability of contractors to work to their originally agreed programme dates and relevent activity durations. This has recently been further confirmed by Stoneman (1979) by the results of some twenty questionnairs which were returned by Sheffield building contractors who were asked to evaluate the major causes of delay in programmed construction projects. Burch (1978) has also analysed certain types of delays in the construction industry. Bor (1977) carried out an analysis of execution time for civil and mechanical engineering projects.

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5.1.2 The Project

Stoneman (1979) carried out research incollaboration with a medium sized building contractor to analyse the actual activity durations for a housing project. He has also compared these durations with those originally programmed. The present research is an extension of Stoneman's work. A number of statistical distributions are fitted to the ratio of programmed and actual durations for the different activities of a housing project. Maximum likelihood method is used for the estimation of parameters of the fitted distribution.

The project chosen was phase 1 of a comprehensive development programme for the construction of 71 bungalows. The total value of the contract at inception was £737,343 although this figure has probably been considerably increased by the completion date, due to variations and the inclusion of the complete community centre building in phase 1. Included in the above figure was an approximate cost breakdown of £8,000 per bungalow as built excluding the costs of district heating, main drainage and certain site works. The contract was subject to adjustment due to increased costs under the application of Part 1 of Section 2 of the Neddo formula rules. The contract works commenced on July 25th, 1977 and the duration, as stated in the Bill of Quantities was 78 weeks with liquidated damages for non-completion included as £2,014 per week (and pro-rata for partial completion).

The contract was awarded to The North East Building Group (Workshop) Ltd. The group consists of three contractors:-

Dernie & Bell, Sons & Co. Ltd.,

J.H. & W.E. Illett Ltd.

J.J. & A.R. Jackson & Co. Ltd.

The phase 1 development contract was carried out by two companies in the group:- Dernie & Bell Ltd., and Jacksons Ltd., who split the work financially approximately equal.

The "ladder-frame" critical path network programme prepared by the contractor to show how he intended planning and carrying out the activities that made up the works to meet the stipulated contract completion time is given in figure 5.1, and table 5.1. "Ladder-frame" relationship of activities in a critical path network is explained in Harris & McCaffer (1977). Woodward (1975) has discussed the advantages and disadvantages of the use of the critical path network method of programming in the construction industry.

5.2 Methodology

In the present research probabilistic analysis of the ratios of actual time to the programmed times is carried out for the two firms and the following main activities:-

1. Activity setting out
2. Activity excavation
3. Activity reinforced concrete foundation
4. Brickwork to damp-proof course
5. Concrete ground floor slab
6. Completion time per bungalow

The actual time, planned time and the ratio of the two for each activity and each firm is given in tables 5.2 - 5.7. The following probability distributions are fitted to the data

1. Weibull
2. Gamma
3. Lognormal
4. Normal

Method of maximum likelihood is used to estimate the parameters of the distribution. Kolmogorov-Smirnov test was applied for the goodness-of-fit of the distribution. Computer programs developed by Dr. A.R.R. Kamath in the Postgraduate School of Industrial Technology were utilized for this purpose. A brief description of the above models, methods of estimation of parameters and tests for the goodness-of-fit is given in the next sections.

Fig. 5.1 SECTION OF "LADDER-FRAME" CRITICAL PATH NETWORK PROGRAMME

Table 5.1

SCHEDULE OF ACTIVITIES AND DURATIONS AS PROGRAMMED FOR EACH INDIVIDUAL BUNGALOW

ACTIVITY	Programmed duration in gang days	Gang size	Total duration time in manhours
1. Setting out	1.0	1 Foreman	8.0
2. Excavation	1.0	1 JCB machine & driver	8.0
3. Concrete foundations	0.66	4 L + 1 ganger	26.0
4. Brickwork to damp-proof course	1.0	4 B + 2 L	48.0
5. Concrete to ground floor slab	0.66	4 L + 1 ganger	26.0
6. Brickwork to super-structure	2.0	4 B + 2 L	96.0
7. Roof carcass	0.66	2 C	10.0
8. Brickwork to gable cut-offs	1.0	4 B + 2L	48.0
*9. Tiling	0.66	2	10.0
*10. Glazing	0.33	2	6.0
11. First fixing-joiner	2.0	2	32.0
*12. First fixing-plumber	1.0	2	16.0
*13. First fixing-electrician	1.0	2	16.0
*14. Plastering	3.0	3 P + 1 L	96.0
15. Second fixing-joiner	3.0	2	48.0
*16. District heating	3.0	2	48.0
*17. Second fixing-electrician	1.0	2	16.0
*18. Second fixing-plumber	2.0	2	32.0
*19. Painting	3.33	3	80.0
*20. Floor Tiling	1.0	1	8.0
21. Clean-out	1.66	1	13.0
22. Snagging	1.66	2	26.0
23. Handover	1.66	1 Foreman	13.0

NOTE:-

* Sub-contractor.

Key L - Labourer B - Bricklayer C - Carpenter P - Plasterer.

Table 5.2

Activity: Setting Out   Planned Time 8 Manhours

	Jacksons		Dernie & Bell (D/B)	
	Actual Time	Actual/Planned Time	Actual Time	Actual/Planned Time
1	1.0	0.125	1.0	0.125
2	1.0	0.125	1.0	0.125
3	1.0	0.125	1.0	0.125
4	1.4	0.175	1.0	0.125
5	1.4	0.175	1.7	0.2125
6	1.4	0.175	1.7	0.2125
7	1.7	0.2125	1.7	0.2125
8	1.7	0.2125	2.7	0.3375
9	1.7	0.2125	2.7	0.3375
10	2.3	0.2875	2.7	0.3375
11	2.3	0.2875	3.25	0.40625
12	2.3	0.2875	3.25	0.40625
13	2.4	0.3	3.25	0.40625
14	2.4	0.3	3.25	0.40625
15	2.4	0.3	4.0	0.5
16	2.4	0.3	4.0	0.5
17	2.5	0.3125	4.0	0.5
18	2.75	0.34375	4.0	0.5
19	2.75	0.34375	4.0	0.5
20	2.75	0.34375	4.0	0.5
21	2.75	0.34375	4.0	0.5
22	4.0	0.5	4.0	0.5
23	4.0	0.5	4.0	0.5
24	4.0	0.5	4.0	0.5
25	4.5	0.5625	4.0	0.5
26	4.5	0.5625	4.0	0.5
27	4.5	0.5625	4.0	0.5
28	4.5	0.5625	4.3	0.5375
29	6.4	0.8	4.3	0.5375
30	6.4	0.8	4.3	0.5375
31	6.4	0.8	5.2	0.65
32	6.4	0.8	5.2	0.65
33	6.5	0.8125	5.2	0.65
34			5.2	0.65
35			5.2	0.65

Table 5.3

Activity: Excavation Planned Time 8 Manhours

	Jacksons		Dernie & Bell (D/B)	
	Actual Time	Actual/Planned Time	Actual Time	Actual/Planned Time
1	3.7	0.4625	7.25	0.90625
2	3.7	0.4625	7.25	0.90625
3	3.7	0.4625	7.25	0.90625
4	4.3	0.5375	7.25	0.90625
5	4.3	0.5375	9.2	1.15
6	4.3	0.5375	9.2	1.15
7	5.1	0.6375	9.2	1.15
8	5.1	0.6375	10.3	1.2875
9	5.1	0.6375	10.3	1.2875
10	5.1	0.6375	10.3	1.2875
11	6.0	0.75	11.8	1.475
12	6.0	0.75	11.8	1.475
13	6.0	0.75	11.8	1.475
14	6.0	0.75	11.8;	1.475
15	6.0	0.75	11.8	1.475
16	6.0	0.75	12.0	1.5
17	6.5	0.8125	12.0	1.5
18	6.5	0.8125	12.0	1.5
19	6.5	0.8125	14.1	1.7625
20	6.5	0.8125	14.1	1.7625
21	6.5	0.8125	14.1	1.7625
22	7.4	0.925	14.1	1.7625
23	7.4	0.925	14.1	1.7625
24	7.4	0.925	15.0	1.875
25	7.4	0.925	15.0	1.875
26	7.4	0.925	15.0	1.875
27	7.75	0.96857	15.0	1.875
28	7.75	0.96875	15.6	1.95
29	7.75	0.96875	15.6	1.95
30	7.75	0.96875	15.6	1.95
31	9.8	1.225	15.6	1.95
32	9.8	1.225	15.6	1.95
33	9.8	1.225	17.2	1.215
34	10.2	1.275	17.2	1.215
35	10.2	1.275	17.2	1.215
36	10.2	1.275		

Table 5.4

Activity: Reinforced Concrete Foundation Planned Time 26 Manhours

	Jackson		Dernie & Bell (D/B)	
	Actual Time	Actual/Planned Time	Actual Time	Actual/Planned Time
1	9.0	0.346	12.5	0.4808
2	9.0	0.346	12.5	0.4808
3	9.0	0.436	12.5	0.4808
4	10.4	0.4	12.5	0.4808
5	10.4	0.4	13.3	0.5115
6	10.4	0.4	13.3	0.5115
7	12.4	0.4769	13.3	0.5115
8	12.4	0.4769	13.6	0.5231
9	12.4	0.4769	13.6	0.5231
10	13.8	0.5308	13.6	0.5231
11	13.8	0.5308	14.8	0.5692
12	13.8	0.5308	14.8	0.5692
13	13.8	0.5308	14.8	0.5692
14	14.5	0.5577	14.8	0.5692
15	14.5	0.5577	17.0	0.6538
16	14.5	0.5577	17.0	0.6538
17	14.5	0.5577	17.0	0.6538
18	16.0	0.6154	19.1	0.7436
19	16.0	0.6154	19.1	0.7436
20	16.0	0.6154	19.1	0.7436
21	16.4	0.6307	19.1	0.7436
22	16.4	0.6307	19.1	0.7436
23	16.4	0.6307	22.6	0.869
24	18.0	0.9623	22.6	0.869
25	18.0	0.9623	22.6	0.869
26	18.0	0.9623	22.6	0.869
27	20	0.7692	22.6	0.869
28	20	0.7692	23.3	0.8961
29	20	0.7692	23.3	0.8961
30	20	0.7692	23.3	0.8961
31	20	0.7692	25.2	0.9692
32	23.8	0.9154	25.2	0.9692
33	23.8	0.9154	25.2	0.9692
34	23.8	0.9154	25.2	0.9692
35	23.8	0.9154	25.2	0.9692
36	23.8	0.9154		

Table 5.5

Activity: Brickwork to damp-proof course   Planned Time 48 Manhours

	Jacksons		Dernie & Bell (D/B)	
	Actual Time	Actual/Planned Time	Actual Time	Actual/Planned Time
1	20	0.4166	10.3	0.2146
2	20	0.4166	10.3	0.2146
3	20	0.4166	10.3	0.2146
4	25	0.5417	11.0	0.2292
5	25	0.5417	11.0	0.2292
6	25	0.5417	11.0	0.2292
7	27.5	0.5729	16.0	0.3333
8	27.5	0.5729	16.0	0.3333
9	27.5	0.5729	16.0	0.3333
10	27.5	0.5729	19.8	0.4125
11	34.6	0.7208	19.8	0.4125
12	34.6	0.7208	19.8	0.4125
13	34.6	0.7208	19.8	0.4125
14	34.6	0.7208	25.0	0.5208
15	34.6	0.7208	25.0	0.5208
16	37.0	0.7708	25.0	0.5208
17	37.0	0.7708	25.2	0.525
18	37.0	0.7708	25.2	0.525
19	48.4	1.0083	25.2	0.525
20	48.4	1.0083	25.2	0.525
21	48.4	1.0083	25.2	0.525
22	48.4	1.0083	26.5	0.552
23	48.4	1.0083	26.5	0.552
24	58.5	1.21875	26.5	0.552
25	58.5	1.21875	26.5	0.552
26	58.5	1.21875	31.6	0.6583
27	58.5	1.21875	31.6	0.6583
28	58.7	1.2229	31.6	0.6583
29	58.7	1.2229	31.6	0.6583
30	58.7	1.2229	31.6	0.6583
31	60	1.25	39.6	0.825
32	60	1.25	39.6	0.825
33	60	1.25	39.6	0.825
34	72	1.5	39.6	0.825
35	72	1.5	39.6	0.825
36	72	1.5		

Table 5.6

Activity: Concrete to Ground Floor Slab   Planned Time 26 Manhours

	Jacksons		Dernie & Bell (D/B)	
	Actual Time	Actual/Planned Time	Actual Time	Actual/Planned Time
1	5.5	0.2115	19.0	0.7308
2	5.5	0.2115	19.0	0.7308
3	5.5	0.2115	19.0	0.7308
4	5.5	0.2115	22.0	0.8461
5	8	0.3077	22.0	0.8461
6	8	0.3077	22.0	0.8461
7	8	0.3077	22.0	0.8461
8	13.3	0.5115	22.0	0.8461
9	13.3	0.5115	22.3	0.8577
10	13.3	0.5115	22.3	0.8577
11	14.7	0.5654	22.3	0.8577
12	14.7	0.5654	25.2	0.9692
13	14.7	0.5654	25.2	0.9692
14	16.0	0.6154	25.2	0.9692
15	16.0	0.6154	25.2	0.9692
16	16.0	0.6154	25.2	0.9692
17	16.4	0.6308	25.3	0.9731
18	16.4	0.6308	25.3	0.9731
19	16.4	0.6308	25.3	0.9731
20	16.4	0.6308	25.3	0.9731
21	16.4	0.6308	26.0	1.0
22	16.8	0.6461	26.0	1.0
23	16.8	0.6461	26.0	1.0
24	16.8	0.6461	26.0	1.0
25	16.8	0.6461	26.0	1.0
26	16.8	0.6461	26.0	1.0
27	18.7	0.7192	26.0	1.0
28	18.7	0.7192	29.2	1.1231
29	18.7	0.7192	29.2	1.1231
30	23.0	0.8846	29.2	1.1231
31	23.0	0.8846	29.2	1.1231
32	23.0	0.8846	29.2	1.1231
33	23.0	0.8846	38.7	1.4885
34	33.3	1.281	38.7	1.4885
35	33.3	1.281	38.7	1.4885
36	33.3	1.281		

Table 5.7

Total Actual Time taken per bungalow: Planned Time 116 Manhours

	Jacksons		Dernie & Bell (D/B)	
	Actual Time	Actual/Planned Time	Actual Time	Actual/Planned Time
1	56	0.4828	58.5	0.5043
2	56	0.4828	58.5	0.5043
3	56	0.4828	58.5	0.5043
4	58	0.5	67.9	0.585
5	58	0.5	67.9	0.585
6	58	0.5	67.9	0.585
7	58	0.5	72.0	0.6270
8	62	0.5345	72.0	0.6270
9	62	0.5345	72.0	0.6270
10	62	0.5345	73.25	0.6315
11	71.1	0.6129	73.25	0.6315
12	71.1	0.6129	73.25	0.6315
13	71.1	0.6129	73.25	0.6315
14	83.9	0.7233	78.1	0.6733
15	83.9	0.7233	78.1	0.6733
16	83.9	0.7233	78.1	0.6733
17	83.9	0.7233	78.1	0.6733
18	83.9	0.7233	87.6	0.755
19	98.1	0.8457	87.6	0.755
20	98.1	0.8457	87.6	0.755
21	98.1	0.8457	87.6	0.755
22	98.8	0.8517	87.6	0.755
23	98.8	0.8517	98.5	0.849
24	98.8	0.8517	98.5	0.849
25	98.8	0.8517	98.5	0.849
26	98.8	0.8517	102.6	0.8845
27	104.9	0.9043	102.6	0.8845
28	104.9	0.9043	102.6	0.8845
29	104.9	0.9043	102.6	0.8843
30	104.9	0.9043	102.6	0.8843
31	112.4	0.969	104.2	0.8928
32	112.4	0.969	104.2	0.8928
33	112.4	0.969	104.2	0.8928
34	113.4	0.9776	104.2	0.8928
35	113.4	0.9776	104.2	0.8928
36	113.4	0.9776		

5.2.1 Statistical Distributions

The following distributions used in the analysis are described in brief.

5.2.1.1 Weibull Distribution

The cumulative distribution for a random variable x distributed as the three-parameter Weibull is given by:

$$F(x;\, \alpha,\, \beta,\, \theta) = \begin{cases} 1 - e^{-\left(\frac{x - \theta}{\alpha}\right)^{\beta}} & x \geq 0 \\ 0 & x < 0 \end{cases} \tag{5.2.1.1.1}$$

where $\beta > 0$, $\alpha > 0$ and $\theta > 0$. The parameter β is called the shape parameter or the Weibull slope, the parameter α is called the scale parameter or the characteristic life, and the parameter θ is called the location parameter.

The two parameter Weibull cumulative distribution is given by

$$F(x;\, \alpha,\, \beta) = \begin{cases} 1 - e^{-\left(\frac{x}{\alpha}\right)^{\beta}} & x \geq 0 \\ 0 & x < 0 \end{cases} \tag{5.2.1.1.2}$$

Since the three-parameter distribution can always be converted to the two-parameter distribution by a simple linear transformation the two-parameter Weibull is used to illustrate the properties of the distribution.

The probability density function is obtained by differentiating (5.2.1.1.2).

$$f(x;\, \alpha,\, \beta) = \begin{cases} \frac{\beta}{\alpha}\left(\frac{x}{\alpha}\right)^{\beta-1} e^{-\left(\frac{x}{\alpha}\right)^{\beta}} & x \geq 0 \\ 0 & x < 0 \end{cases} \tag{5.2.1.1.3}$$

The kth moment of the Weibull distribution is found as follows:

$$E(X^k) = \int_0^\infty x^k \frac{\beta}{\alpha} \left(\frac{x}{\alpha}\right)^{\beta-1} e^{\left(\frac{-x}{\alpha}\right)^{\beta}} dx \quad . \tag{5.2.1.1.4}$$

Using the transformation $u = \left(\frac{x}{\alpha}\right)^{\beta}$ one gets

$$E(X^k) = \alpha^k \Gamma\left(1 + \frac{k}{\beta}\right) \quad . \tag{5.2.1.1.5}$$

Hence the mean of the Weibull distribution is

$$\mu = \alpha \Gamma \left(1 + \frac{1}{\beta}\right) \quad , \tag{5.2.1.1.6}$$

and the variance is

$$\sigma^2 = \alpha^2 \left[\Gamma \left(1 + \frac{2}{\beta}\right) - \Gamma^2 \left(1 + \frac{1}{\beta}\right)\right] \tag{5.2.1.1.7}$$

parameter β , as the name implies, determines the shape of the distribution.

5.2.1.2 Gamma distribution

The gamma probability density function is

$$f(x;\ \mu,\ \lambda) = \begin{cases} \dfrac{\lambda^{\mu}}{\Gamma(\mu)}\, x^{\mu-1}\, e^{-\lambda x} & x \geq 0,\ \lambda > 0,\ \mu > 0 \\ 0 & \text{elsewhere} \end{cases} \tag{5.2.1.2.1}$$

where $\Gamma(\mu)$ is given by

$$\Gamma(\mu) = \int_0^\infty x^{\mu-1}\, e^{-x}\, dx \tag{5.2.1.2.2}$$

and $\Gamma(\mu) = (\mu - 1)!$ when μ is a positive integer. μ and λ are shape and scale parameters respectively. The cumulative gamma distribution is

$$F(t) = \begin{cases} \dfrac{\lambda^{\mu}}{\Gamma(\mu)} \displaystyle\int_0^t x^{\mu-1} e^{-\lambda x}\, dx & x \geqslant 0 \\ 0 & x < 0 \end{cases} \qquad (5.2.1.2.3)$$

If μ is an integer, it can be shown that

$$F(t) = \sum_{k=\mu}^{\infty} \frac{(\lambda t)^k}{k!} e^{-\lambda t} \quad . \qquad (5.2.1.2.4)$$

The mean and variance of the gamma distribution are given by

Mean = $\mu\lambda$

Variance = $\mu\lambda^2$

5.2.1.3 Lognormal distribution

The lognormal distribution is the model for a random variable whose logarithm follows the normal distribution with parameters μ and σ. Thus

$$f(x;\ \mu,\ \sigma) = \begin{cases} \dfrac{1}{\sigma x\sqrt{2\pi}} \exp\left[-\dfrac{1}{2\sigma^2}[\ \ln(x) - \mu]^2\right] & 0 < x < \infty \\ 0 & \text{otherwise} \end{cases} \qquad (5.2.1.3.1)$$

μ and σ are scale and shape parameters respectively. This distribution has many different shapes for non-negative x. The lognormal distribution has been used in a variety of applications, from economics to biology, for processes in which the observed value is a random proportion of the previous value. Examples include the distribution of personal incomes, inheritancies, and bank deposits, and the distribution of the size of an organisation whose growth is subject to many small impulses, the effect of which is proportional to the momentary size of the organisation.

The mean of the lognormal distribution is given as

$$E(x) = \exp\left(\mu + \frac{\sigma^2}{2}\right) \qquad (5.2.1.3.2)$$

and the variance as

$$\text{var}(x) = e^{2\mu + \sigma^2}\,(e^{\sigma^2} - 1) \qquad (5.2.1.3.3)$$

The cumulative distribution function for the lognormal is

$$F(x) = \int_{\sigma}^{x} \frac{1}{x\sigma\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left\{\frac{\ln(x) - \mu}{\sigma}\right\}^2\right] dx \qquad (5.2.1.3.4)$$

or

$$F(x) = \Phi\left(\frac{\ln(x) - \mu}{\sigma}\right)$$

where Φ is the cumulative distribution function of standard normal. The μ and σ, are, respectively the mean and standard deviation of the natural logarithm of the random variable x.

5.2.1.4 Normal Distribution

Either as an exact probability model or as a good approximate to the exact probability model, the normal distribution provides a good description for many situations. A random variable X is said to be noramlly distributed (or have a normal probability distribution) with mean μ, and standard deviation σ when its probability density function is given by

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left\{\frac{x - \mu}{\sigma}\right\}^2\right], \qquad \begin{array}{l}\sigma > 0 \\ -\infty < x < \infty \\ -\infty < \mu < \infty\end{array} \qquad (5.2.1.4.1)$$

The distribution in this form is usually referred to as $N(\mu,\sigma^2)$, where σ^2 be the variance.

When $\mu = 0$, and $\sigma = 1$, then we call X a standard normal variable with standard normal probability density and distribution functions.

Let $z = (x - \mu)/\sigma$ be the standardized normal variable. Distribution of z is the standard normal distribution function which is denoted by N(0; 1) and can be expressed as,

$$f(z) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{z^2}{2}\right), \qquad -\infty < z < \infty \qquad (5.2.1.4.2)$$

The normal cumulative distribution function is given by

$$F(x) = \int_{-\infty}^{x} f(x)\, dx \qquad (5.2.1.4.3)$$

Tabulated values of the standard normal C.D.F. integral are available and can be obtained from any statistical tables. However, there are a number of approximate mathematical functions that can be utilized to evaluate Eq. (5.2.1.4.3). A fairly accurate mathematical formula was introduced by Page (1977) and is given by

$$F(z) = \frac{1}{2\pi} \int_{-\infty}^{z} \exp\left(-\frac{1}{2} z^2\right) dz \qquad (5.2.1.4.4)$$

$$F(z) = 0.5\ [1 + \tan h(y)] \qquad (5.2.1.4.5)$$

where $y = \sqrt{2/\pi}\ (1 + 0.044715\ z^2)\ z$

$z = (x - \mu)/\sigma$

The main characteristics of normal distribution are as follows:

(1) It is bell-shaped and symmetrical about $x = \mu$.

(2) There is a single mode at $x = \mu$, which is also the median.

(3) It is the limiting distribution for many distributions, e.g. gamma distribution as the shape parameter tends to infinity.

Given a set of data $x_1, x_2, \ldots, x_n$, the maximum likelihood estimates for μ and σ are

$$\hat{\mu} = \frac{1}{n} \sum_{i=1}^{n} x_i = \bar{x} \qquad (5.2.1.4.6)$$

$$\hat{\sigma}^2 = \frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^2 \qquad (5.2.1.4.7)$$

5.2.2 Methods for the Estimation of Parameters of Distribution

A number of methods are available for the estimation of parameters for a hypothised distribution. The most important of them and commonly used are:

(1) Method of Maximum Likelihood.

(2) Method of Least Squares.

(3) Method of Matching Moments.

(4) Graphical Methods.

The above methods are briefly described in the following sections.

5.2.2.1 Method of Maximum Likelihood

This method is due to Fisher (1922) and is based on the principle that the probability of obtaining the given sample values should be a maximum if the estimator equals the population value.

Suppose there is a sample $x_1, \ldots, x_n$ from a distribution (x, θ), where θ is the population parameter. The likelihood function of the n independent sample values is defined as

$$L\,(x_1, x_2, \ldots, x_n; \theta)$$

i.e.

$$L = \prod_{i=1}^{n} f(x_i\,;\,\theta) \qquad (5.2.2.1.1)$$

The method of maximum likelihood consists of finding the value θ which maximises $L\,(x_1, x_2, \ldots; \theta)$. It is convenient to take the logarithm of the likelihood function, thus

$$\ln L = \mathcal{L}\,(\theta) = \ln \prod_{i=1}^{n} f(x_i\,;\,\theta) \qquad (5.2.2.1.2)$$

$$= \sum_{i=1}^{n} \ln f(x_i\,;\,\theta)$$

called the "log-likelihood function". The position of the maxima of $\ln L$ and $\mathcal{L}$ are identical.

5.2.2.2 Method of Least Squares

The method of least squares is widely used in fitting a curve or a straight line to a given set of data. It is based on the principle that the sum of the squares of the errors or differences between the actual and corresponding curve values is a minimum.

Let $y_1, y_2, y_3, \ldots y_n$ be a set of n observations taken at points $x_1, x_2, \ldots x_n$ respectively.

Let $y_i' = f(x; \theta_j, j = 1, 2, \ldots m)$ be a function representing values on the fitted curve, where θ_j are the parameters to be estimated.

Then

$$D^2 = \sum_{i=1}^{n} [y_i - f(x_i ; \theta_j , j = 1, \ldots m)]^2 \text{ is minimum.}$$

This is obtained by setting the first m partial derivates of D^2 w.r.t. to its parameters $\theta_1, \theta_2, \ldots \theta_m$ to zero and solving the set of m 'normal equations' for m parameters.

$$\text{i.e. } \frac{\partial D^2}{\partial \theta_j} = 0 \quad \text{for } j = 1, \ldots m.$$

In case of a straight line y = ax + b.

$$D^2 = \sum_{i=1}^{n} \{y_i - (ax_i + b)\}^2$$

where (x_i, y_i), i = 1, ...n are the data points. Then $\frac{\partial D^2}{\partial a} = 0$

gives $\sum_{i=1}^{n} 2\{y_i - (ax_i + b)(-x_i) = 0$

$$\text{i.e. } -\sum_{i=1}^{n} y_i x_i + a \sum_{i=1}^{n} x_i^2 + b \sum_{i=1}^{n} x_i = 0 \qquad (5.2.2.2.1)$$

$$\frac{\partial D^2}{\partial b} = 0 = \sum_{i=1}^{n} 2\{y_i - (ax \quad b)\} = 0$$

$$\sum_{i=1}^{n} y_i - a \sum_{i=1}^{n} x_i - b \sum_{i=1}^{n} 1 = 0 \qquad (5.2.2.2.2)$$

The least square estimates of parameters a and b are obtained by solving the above normal equations (5.2.2.2.1) and (5.2.2.2.2)

$$a^{*} = \frac{n \sum_{i=1}^{n} x_i y_i - \left[\sum_{i=1}^{n} x_i\right]\left[\sum_{i=1}^{n} y_i\right]}{n \sum_{i=1}^{n} x_i^2 - \sum_{i=1}^{n} x_i} \qquad (5.2.2.2.3)$$

$$b^{*} = \frac{\left[\sum_{i=1}^{n} x_i^2\right]\left[\sum_{i=1}^{n} y_i\right] - \left[\sum_{i=1}^{n} x_i y_i\right]\left[\sum_{i=1}^{n} x_i\right]}{n \sum_{i=1}^{n} x_i^2 - \left[\sum_{i=1}^{n} x_i\right]^2} \qquad (5.2.2.2.4)$$

5.2.2.3 Method of matching moment

Suppose that X is either a continuous random variable with probabiltiy density $f(x;\ \theta_1, \theta_2, \ldots \theta_k)$ or a discrete random variable with distribution $P(x;\ \theta_1, \theta_2, \ldots \theta_k)$ characterised by k unknown parameters Let X1, X2, ..., X_n be a random sample of size n from X, and define the first k sample moments about the origin as

$$m_t' = \frac{\sum_{i=1}^{n} X_i^t}{n} \qquad t = 1, 2, \ldots k \qquad (5.2.2.3.1)$$

The first k population theoretical moments about the origin are

$$\mu_t' = E(X^t) = \int_{-\infty}^{\infty} x^t\ f(x;\ \theta_1, \theta_2, \ldots \theta_k)\ dx \qquad (5.2.2.3.2)$$

$t = 1, 2, \ldots k$ X continuous

$$= \sum_{x \in R_x} x^t\ p(x;\ \theta_1, \theta_2, \ldots \theta_k) \qquad (5.2.2.3.3)$$

$t = 1, 2, \ldots k$ X discrete.

The population moments $\{\mu_t'\}$ will, in general, be functions of the k unknown parameters $\{\theta_i\}$. Equating sample moments and population moments will yield k simultaneous equations in k unknowns (the $\{\theta_i\}$); that is,

$$\mu_t' = m_t' \qquad t = 1, 2, \ldots k \tag{5.2.2.3.4}$$

The solution to equation (5.2.2.3.4) denoted $\hat{\theta}_1, \hat{\theta}_2, \ldots \hat{\theta}_k$, yields the moment estimates of $\theta_1, \theta_2, \ldots \theta_k$.

The method of matching moments often yields estimators that are reasonably good. In general, matching moment estimators are asymptotically normally distributed (approximately) and consistent. However, their variance may be larger than the variance of estimators derived by other methods, such as the method of maximum likelihood. Occassionally, the method of matching moments yields estimators that are very poor.

5.2.2.4 Graphical Methods of estimation

Graphical methods, are the simplest, but not very accurate methods of estimating distribuiton parameters. However, they have many particular advantages in the early states of data anaysis.

It is usually possible to draw a smooth curve (of unknown form) through experimental points plotted so that a correlation exists between the abscissa and ordinate. However, it is not usually possible to tell from visual examination of given curve, the equation describing it, until the curve is a straight line. Straight line is therefore taken as a basis of visual graphical analysis. However, if the functional form is non-linear, then usually a suitable transformation can be applied to reduce it to linear form. In number of situaion logarithm transformation is very helpful. For this purpose log and semi-log and probability grpah papers (for various distributions) are available.

Much of the theoretical foundation for graphical methods is given in Gumble (1958). Johnson (1959) developed simplified methods for estimation of parameters and for drawing confidence intervals for regression lines, and Herd (1960) provided interpretive analysis of graphical plots. Hans & Shapiro (1967) have demonstrated the use of probability plots for estimating distribution parameters, as well as for evaluating the applicability of the various probability models such as Normal, Lognormal, Gamma, Chi-Square, Exponential, Weibull, Beta and Uniform distributions.

5.2.3 Testing Goodness-of-Fit of Distributions

Goodness-of-fit tests are statistical procedures which can be utilized to test the goodness fit of a particular set of data to hypothesized distribution. Two simple tests i.e. of Chi-Square or Kolmogorov-Smirnov are commonly used for this purpose. The Kolmogorov-Smirnov test is particularly well suited for testing when the hypothesized distribuion is continuous.

5.2.3.1 Chi-Square test for Goodnes-of-Fit

The oldest and most commonly used procedure for evaluating distributional assumptions is the Chi-Square Goodness-of-Fit Test. It can be applied simply to test any distributional assumption, without our having to know the values of the distribution parameters. Its major drawbacks are its lack of sensitivity in detecting inadequate models when few observations are available, and the frequent need to arrange the data into arbitrary cells, which can affect the outcome of the test.

The null hypothesis of the test is that a set of data comes from a population having a given distribution (against the alternative that the population has some other distribution) and is based on the statistic

$$\chi^2 = \sum_{i=1}^{k} \frac{(f_i - e_i)^2}{e_i}$$

where the f_i and e_i are the corresponding observed and expected frequencies. The sampling distribution of this statistic is approximately the Chi-Square distribution with k - m degrees of freedom, where k is the number of cells in the formulae for χ^2 and m is the number of quantities, obtained from the observed data, that are used in calculating the expected frequencies.

5.2.3.2 Kolmogorov-Smirnov Test

The Kolmogorov-Smirnov test the hypothesis that a random sample belongs to a specified continuous distribution.

Let t_i, i = 1, ... N be observed values arranged in an ascending order. The observed cumulative distribuion function is given by

$$G(t_i) = \frac{i}{N} \qquad i = 1, 2, \ldots N \qquad (5.2.3.2.1)$$

where i is the number of observations in the sample not greater than t in magnitude. The test statistic called D-Max is then given by

$$\text{D-Max} = \max_{i=1,\ldots,N} |F(t_i) - G(t_i)| \qquad (5.2.3.2.2)$$

where $F(t_i)$ is the value of the cumulative distribution function obtained from the hypothesised distribution.

The hypothesis H_0: F(t) = G(t), is rejected at the 100% level of significance if the computed value of the statistic exceeds the 100 α% point of the theoretical distribution of the ststistic chosen.

Critical values of the Kolmogorov-Smirnov test for different significance levels are tabulated in Appendix E.. Although the Kolmogorov-Smirnov test gives better results for small sample size, it is safer to use the χ^2-goodness-of-fit test if one is dealing with large samples.

5.3 Comments and Discussion

(1) Activity: Setting Out

(a) It can be seen from the summary table 5.8 and fig. 5.2 that all four distributions provide a reasonable fit to to the activity duration.

(b) For Jacksons data all four distributions provide comparable mean values. However Weibull provide the smallest variance for the activity and Lognormal the smallest D-max.

(c) For the Dernie & Bell data, the lognormal provides a slightly larger mean than the other three distributions with the Weibull having the smallest variance, and the normal the smallest D-max (table 5.8 and fig. 5.3).

(2) Activity: Excavation

(a) For Jackson's data, table 5.9 and fig. 5.4, show that all the four distributions have nearly equal means. However the Normal provides a smaller variance and D-max than the other three distributions.

(b) For the Dernie & Bell data, the Weibull distribution provide a better fit than the other three distributions in terms of minimum mean, variance and D-max as shown in table 5.9 and fig. 5.5.

(3) Activity: <u>Reinforced Concrete Foundation</u>

(a) Table 5.10 and fig. 5.6 that give the results for the Jackson's data show that all four distributions provide nearly equal means and variance, whilst the Lognormal distribution gives the smallest D-max.

(b) For the Dernie & Bell data, all the four distributions result in nearly equal means and variances. All distributions except Gamma also provide approximately equal D-max. (Table 5.10 and fig. 5.7.)

(4) Activity: <u>Brickwork and Damp-proof course</u>

(a) For Jackson's data table 5.11 and fig. 5.8 show that means of the four distributions are all nearly equal, the Weibull however provides a better fit in terms of a minimum variance and D-max.

(b) Table 5.11 and fig. 5.9 show that for the Dernie & Bell data the means of all four distributions are nearly all equal, while the Weibull provides the smallest variance, and the Normal the smallest D-max.

(5) Activity: <u>Concrete to Ground Floor Slab</u>

(a) The Weibull distribution provides the best fit for the Jackson data as shown in table 5.12 and fig. 5.9.

(b) For the Dernie & Bell data, table 5.12 and fig. 5.10 demonstate that all four distributions have nearly equal means, while the Gamma has the smallest variance and D-max.

(6) Distribution of the Ratio of Actual/Planned time per bungalow

For both firms the Weibull distribution provides a better fit than the other three distributions in terms of minimum mean, variance and D-max. This is demonstrated in table 5.13 and figs. 5.11 and 5.12.

Table 5.8 Summary of Comparison of Goodness-of-Fit of the Weibull, Gamma, Lognormal and Normal Distributions

Activity 1 Setting Out

			Jacksons	Dernie & Bell
Maximum Likelihood Estimates	Weibull	Shape	1.9711	3.1514
		Scale	0.45	0.48
		Mean	0.4	0.43
		Variance	0.04438	0.0226
		D-max	0.19	0.272
	Gamma	Shape	3.471	5.1357
		Scale	0.114	0.0842
		Mean	0.4	0.43
		Variance	0.045	0.03
		D-max	0.148	0.338
	Lognormal	Shape	0.57	0.51
		Scale	-1.0783	-0.9387
		Mean	0.4	0.44
		Variance	0.0605	0.0583
		D-max	0.129	0.286
	Normal	Mean	0.3954	0.4325
		Std. Dev.	0.22	0.16
		Variance	0.0477	0.0259
		D-max	0.23	0.262

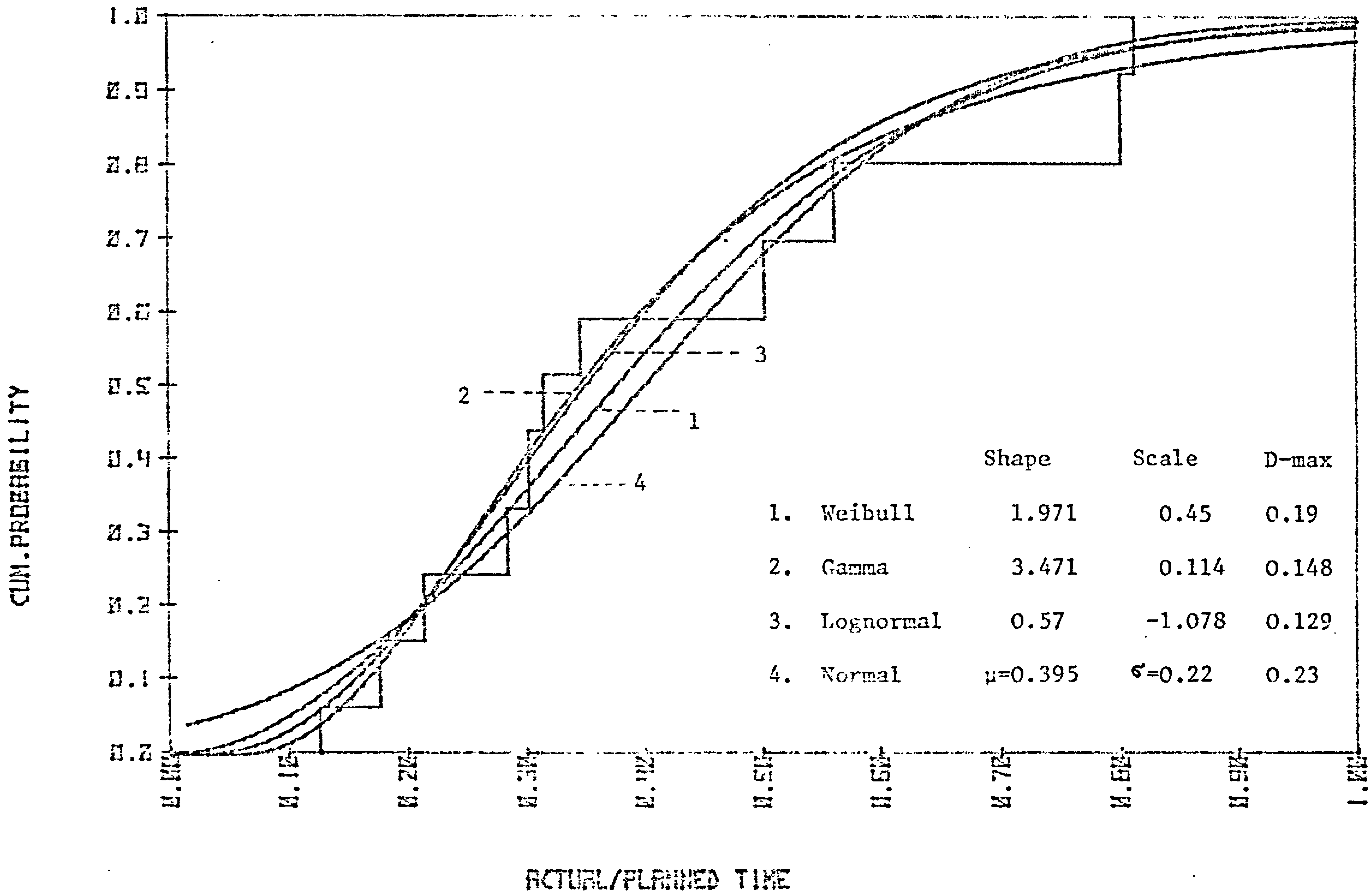


Fig. 5.2 Cumulative Distribution Function Plots of Activity Setting Out for Jacksons

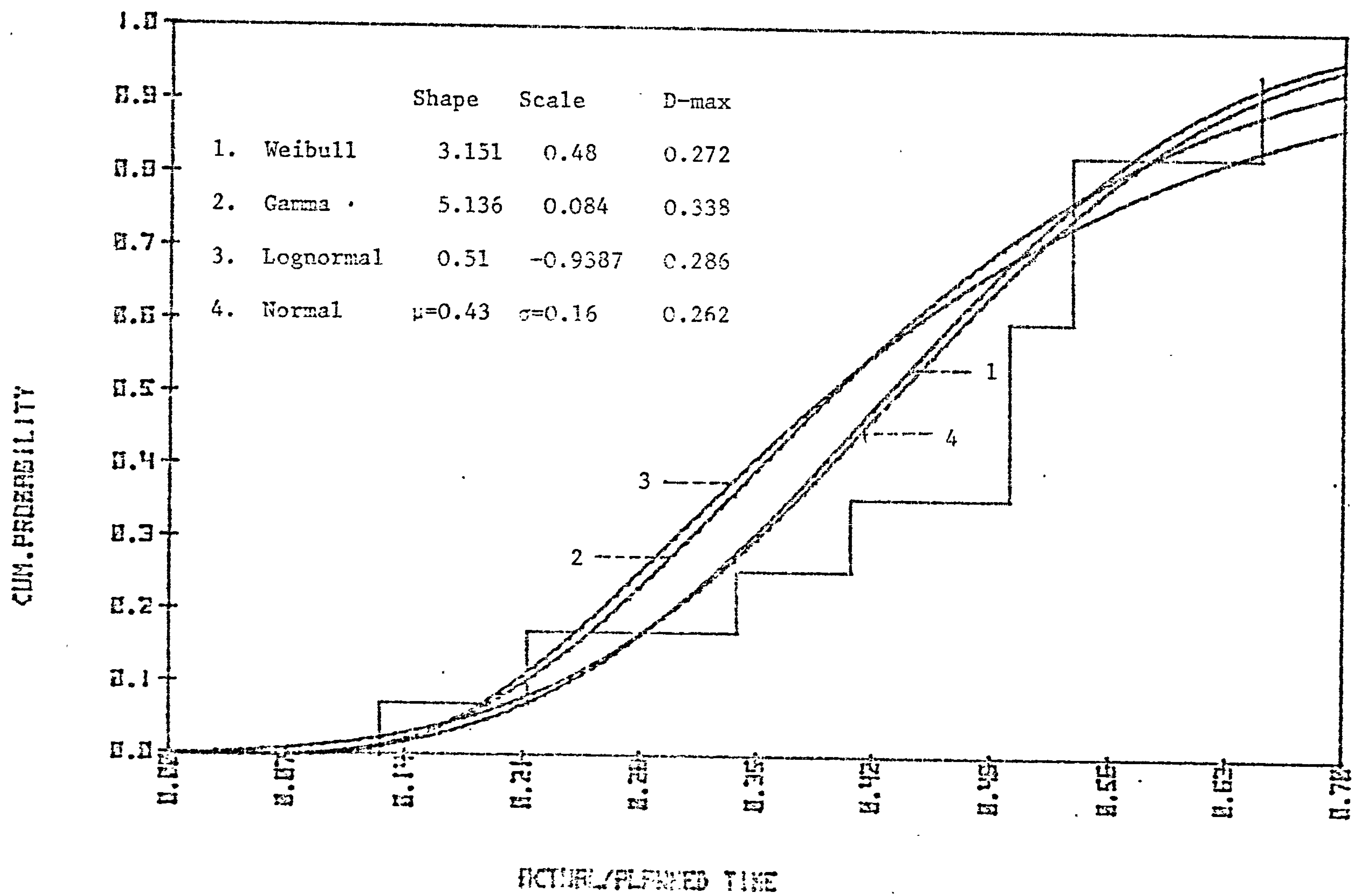


Fig. 5.3 Cumulative Distribution Function Plots of Activity Setting Out for Dernie & Bell

Table 5.9 Comparison of Goodness-of-Fit of the Weibull, Gamma, Lognormal and Normal Distributions

Activity 2 Excavation

			Jacksons	Dernie & Bell
Maximum Likelihood Estimates	Weibull	Shape	3.8257	5.0608
		Scale	0.93	1.73
		Mean	0.84	1.57
		Variance	0.0597	0.129
		D-max	0.137	0.157
	Gamma	Shape	12.2334	16.097
		Scale	0.0684	0.0982
		Mean	0.84	1.58
		Variance	0.06	0.15
		D-max	0.154	0.214
	Lognormal	Shape	0.3	0.26
		Scale	-0.22	0.4265
		Mean	0.84	1.59
		Variance	0.0641	0.179
		D-max	0.132	0.189
	Normal	Mean	0.8365	1.5807
		Std. Dev.	0.24	0.38
		Variance	0.058	0.143
		D-max	0.125	0.17

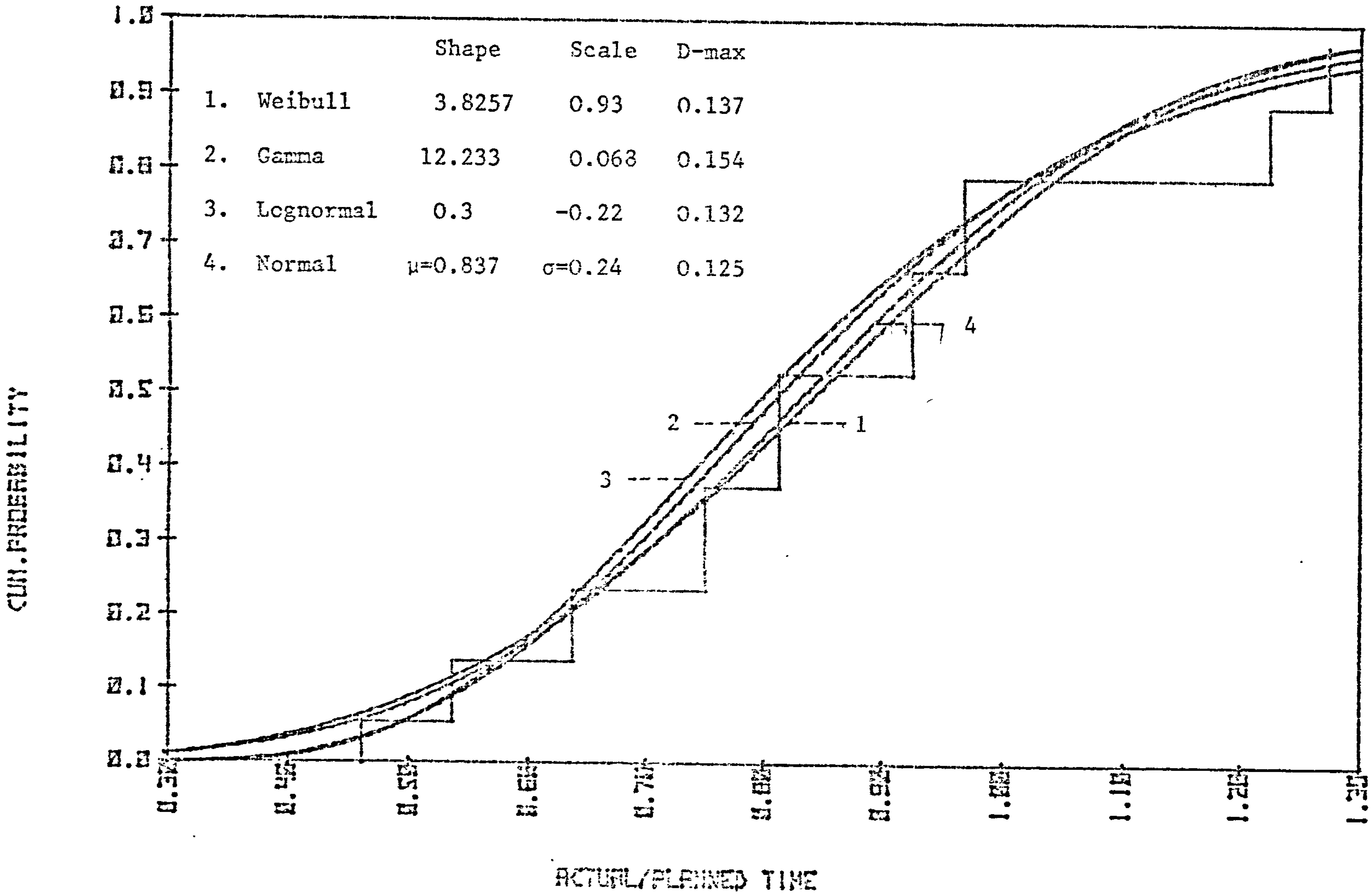


Fig. 5.4 Cumulative Distribution Function Plots of Activity Excavation for Jacksons

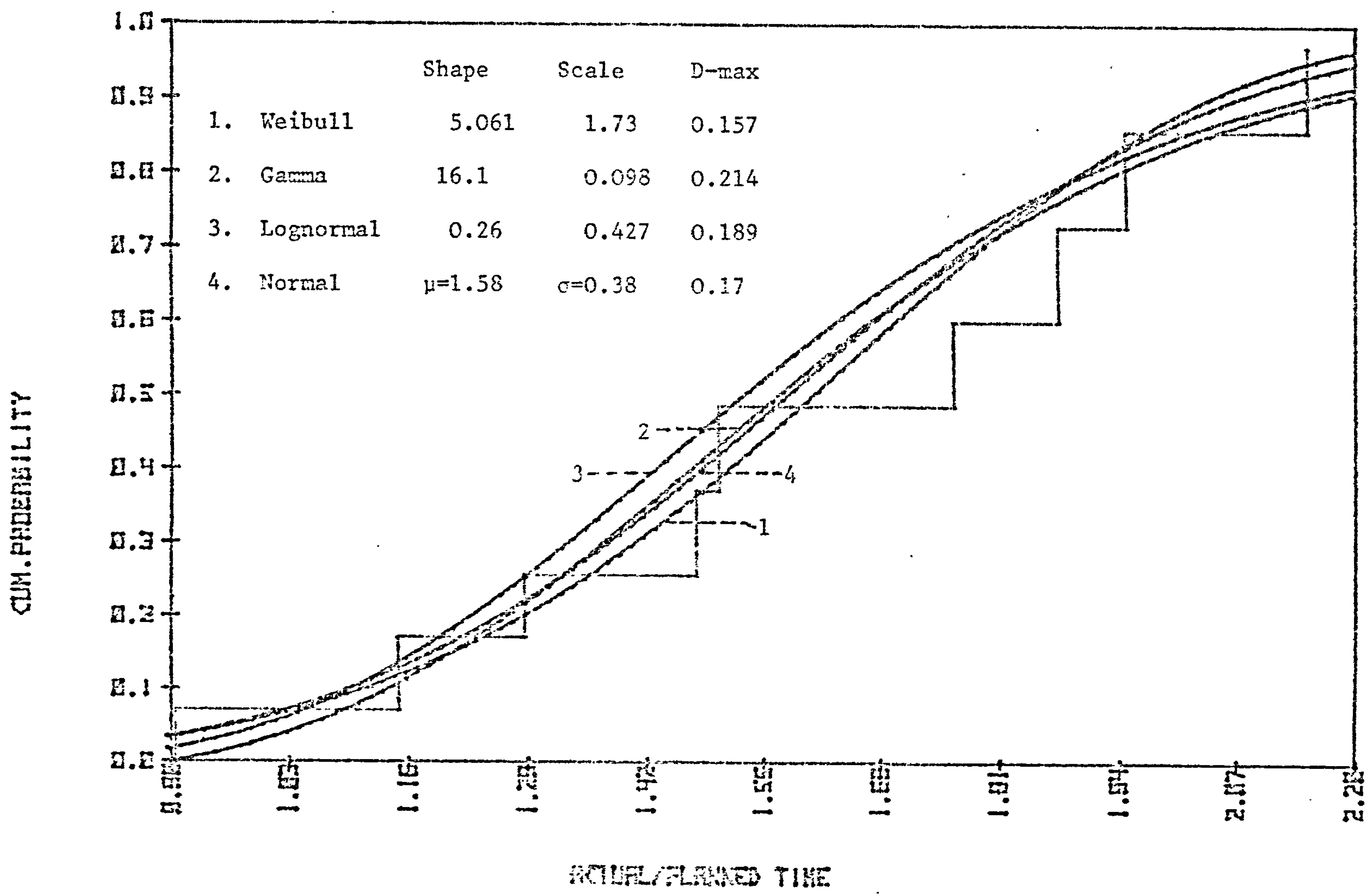


Fig. 5.5 Cumulative Distribution Function Plots of Activity Excavation for Dernie & Bell

Table 5.10 Comparison of Goodness-of-Fit of the Weibull, Gamma, Lognormal and Normal Distributions

Activity 3 Reinforced Concrete Foundation

			Jacksons	Dernie & Bell
Maximum Likelihood Estimates	Weibull	Shape	3.993	4.55
		Scale	0.68	0.78
		Mean	0.62	0.71
		Variance	0.0302	0.0315
		D-max	0.121	0.187
	Gamma	Shape	12.912	15.925
		Scale	0.04787	0.0445
		Mean	0.62	0.71
		Variance	0.03	0.03
		D-max	0.139	0.25
	Lognormal	Shape	0.29	0.26
		Scale	-0.5199	-0.3755
		Mean	0.62	0.71
		Variance	0.0333	0.032
		D-max	0.097	0.186
	Normal	Mean	0.62	0.7091
		Std. Dev.	0.17	0.18
		Variance	0.0298	0.032
		D-max	0.11	0.186

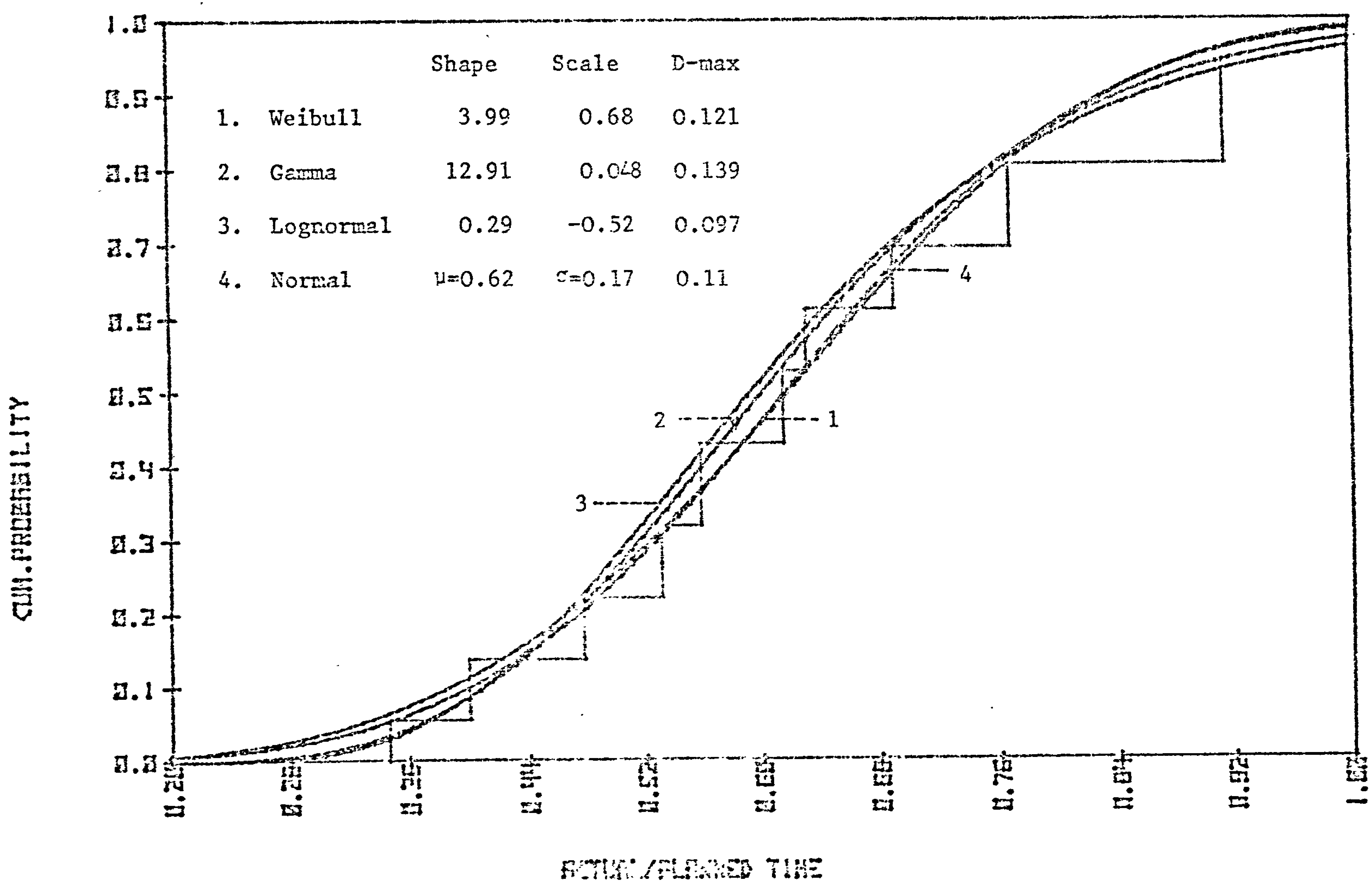


Fig. 5.6 Cumulative Distribution Function Plots of Activity Reinforced Concrete Foundation for Jacksons

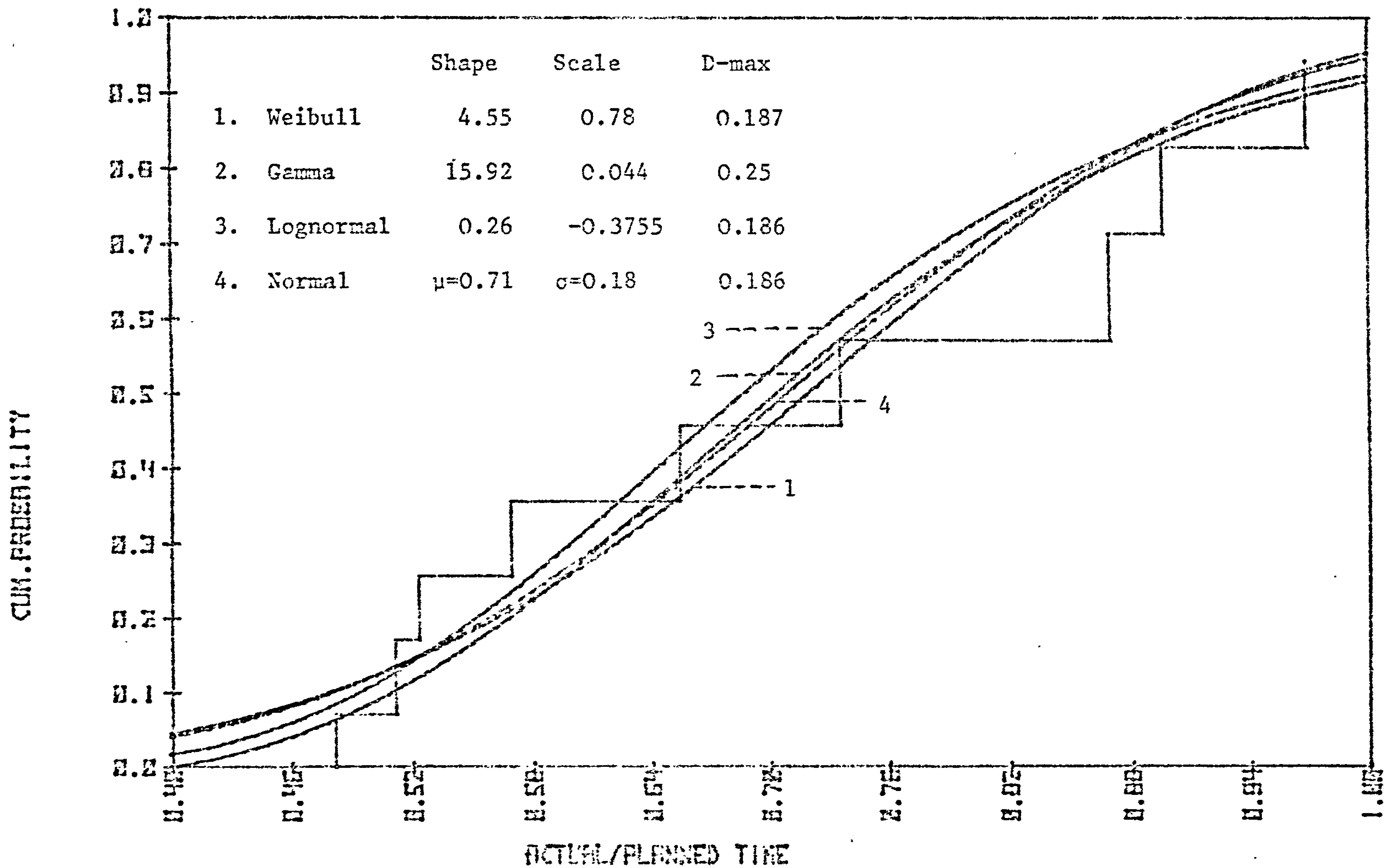


Fig. 5.7 Cumulative Distribution Function Plots of Activity Reinforced Concrete Foundation for Dernie & Bell

Table 5.11 Comparison of Goodness-of-Fit of the Weibull, Gamma, Lognormal, Normal Distributions

Activity 4 Brickwork to Damp-proof Course

			Jacksons	Dernie & Bell
Maximum Likelihood Estimates	Weibull	Shape	3.0811	2.993
		Scale	1.03	0.57
		Mean	0.92	0.51
		Variance	0.10608	0.03444
		D-max	0.178	0.161
	Gamma	Shape	7.17579	6.40847
		Scale	0.12748	0.0793
		Mean	0.91	0.51
		Variance	0.12	0.04
		D-max	0.242	0.188
	Lognormal	Shape	0.39	0.43
		Scale	-0.1609	-0.7566
		Mean	0.92	0.51
		Variance	0.14098	0.0524
		D-max	0.18	0.225
	Normal	Mean	0.9144	0.5084
		Std. Dev.	0.34	0.19
		Variance	0.11263	0.0366
		D-max	0.179	0.154

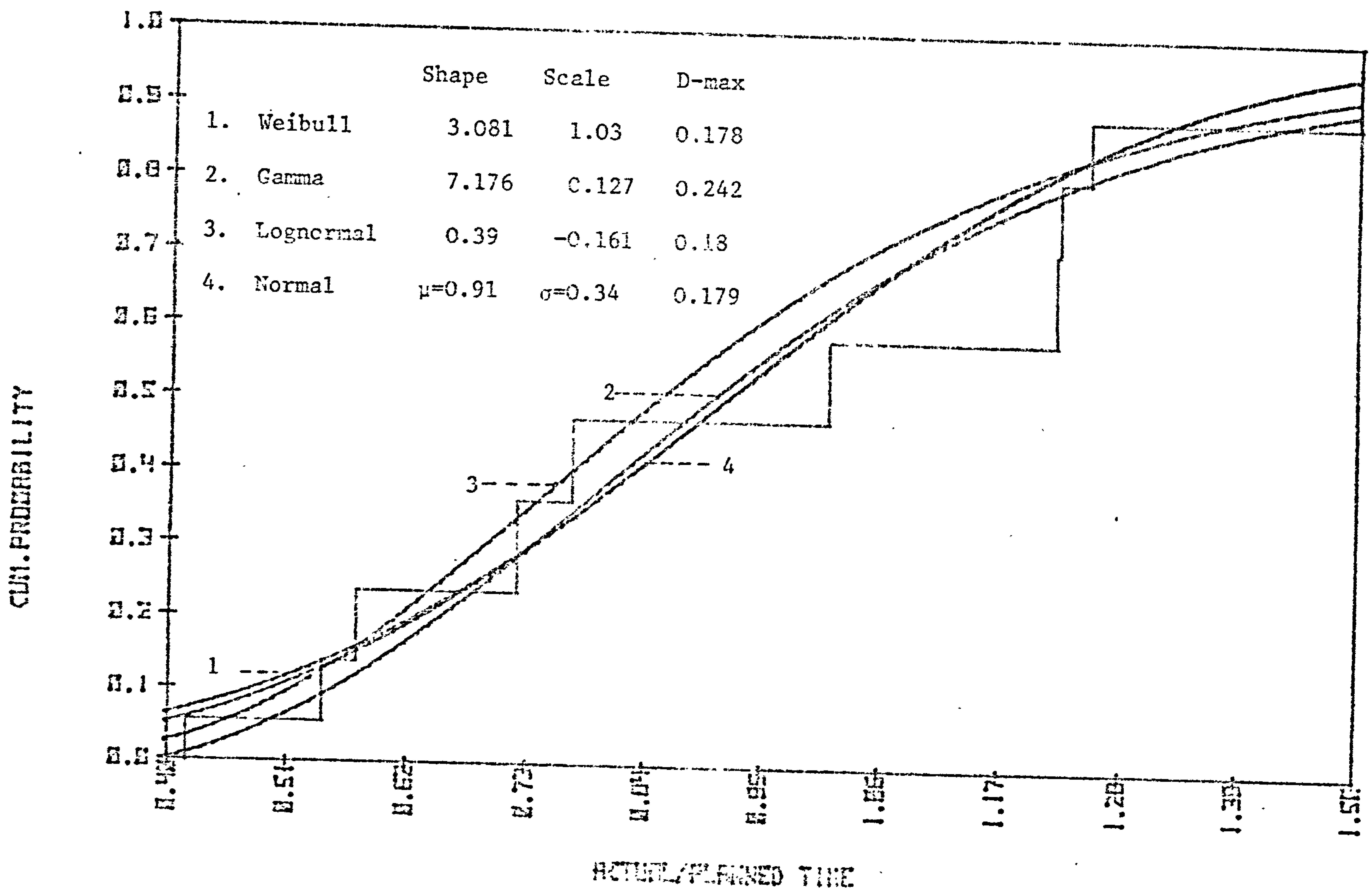


Fig. 5.3 Cumulative Distribution Function Plots of Activity Brickwork to Damp-proof Course for Jacksons

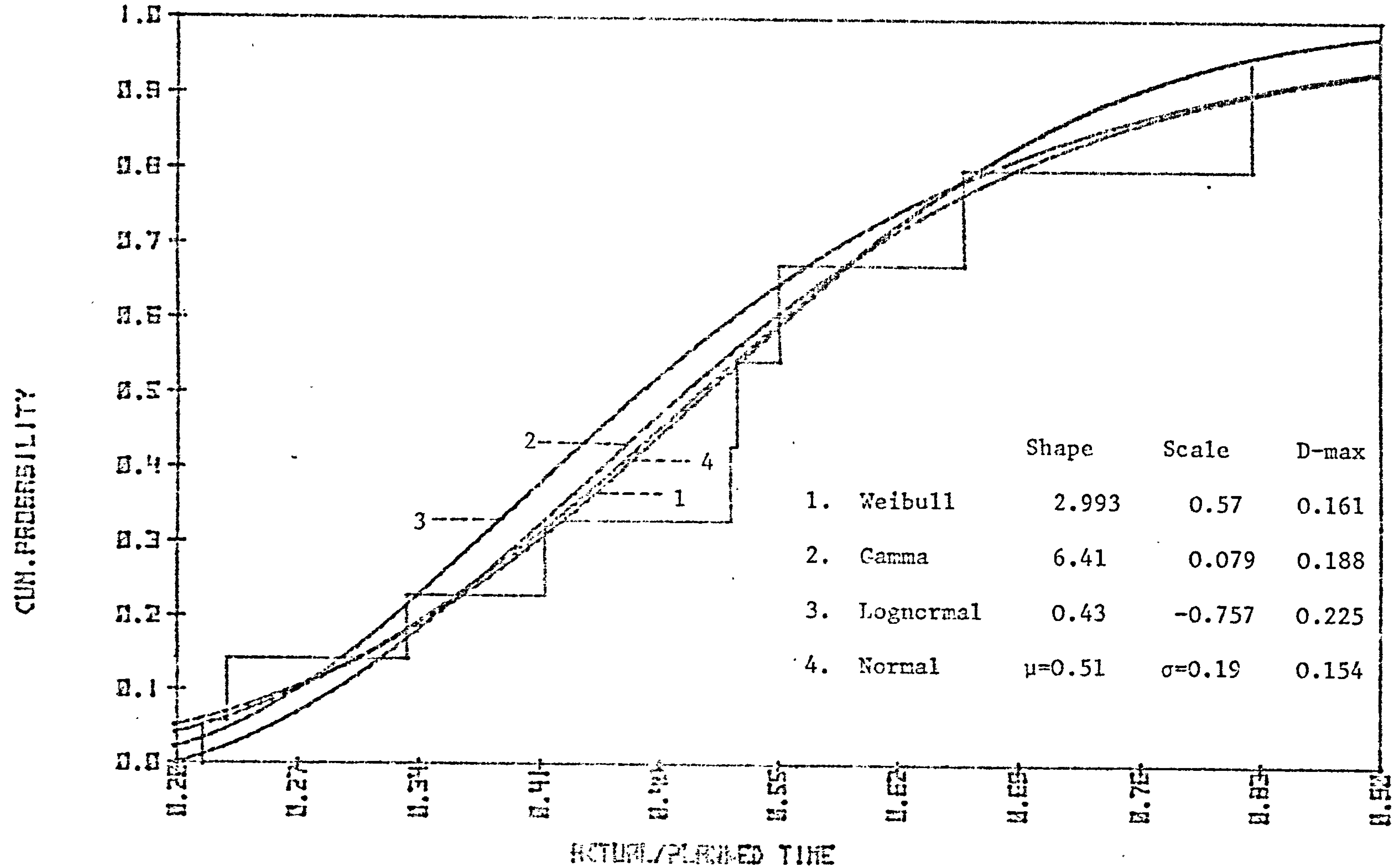


Fig. 5.9 Cumulative Distribution Function Plots of Activity Brickwork to Damp-proof Course for Dernie & Bell

Table 5.12 Comparison of Goodness-of-Fit of the Weibull, Gamma, Lognormal and Normal Distributions

Activity 5 Concrete to Ground Floor Slab

			Jacksons	Dernie & Bell
Maximum Likelihood Estimates	Weibull	Shape	2.485	4.988
		Scale	0.71	1.08
		Mean	0.63	0.99
		Variance	0.07407	0.05 35
		D-max	0.179	0.27
	Gamma	Shape	5.06975	31.9336
		Scale	0.12475	0.0312
		Mean	0.63	1.0
		Variance	0.08	0.03
		D-max	0.211	0.142
	Lognormal	Shape	0.48	0.18
		Scale	-0.5598	-0.0204
		Mean	0.64	1.0
		Variance	0.108	0.03115
		D-max	0.215	0.225
	Normal	Mean	0.6325	0.9954
		Std. Dev.	0.27	0.19
		Variance	0.0749	0.03582
		D-max	0.202	0.262

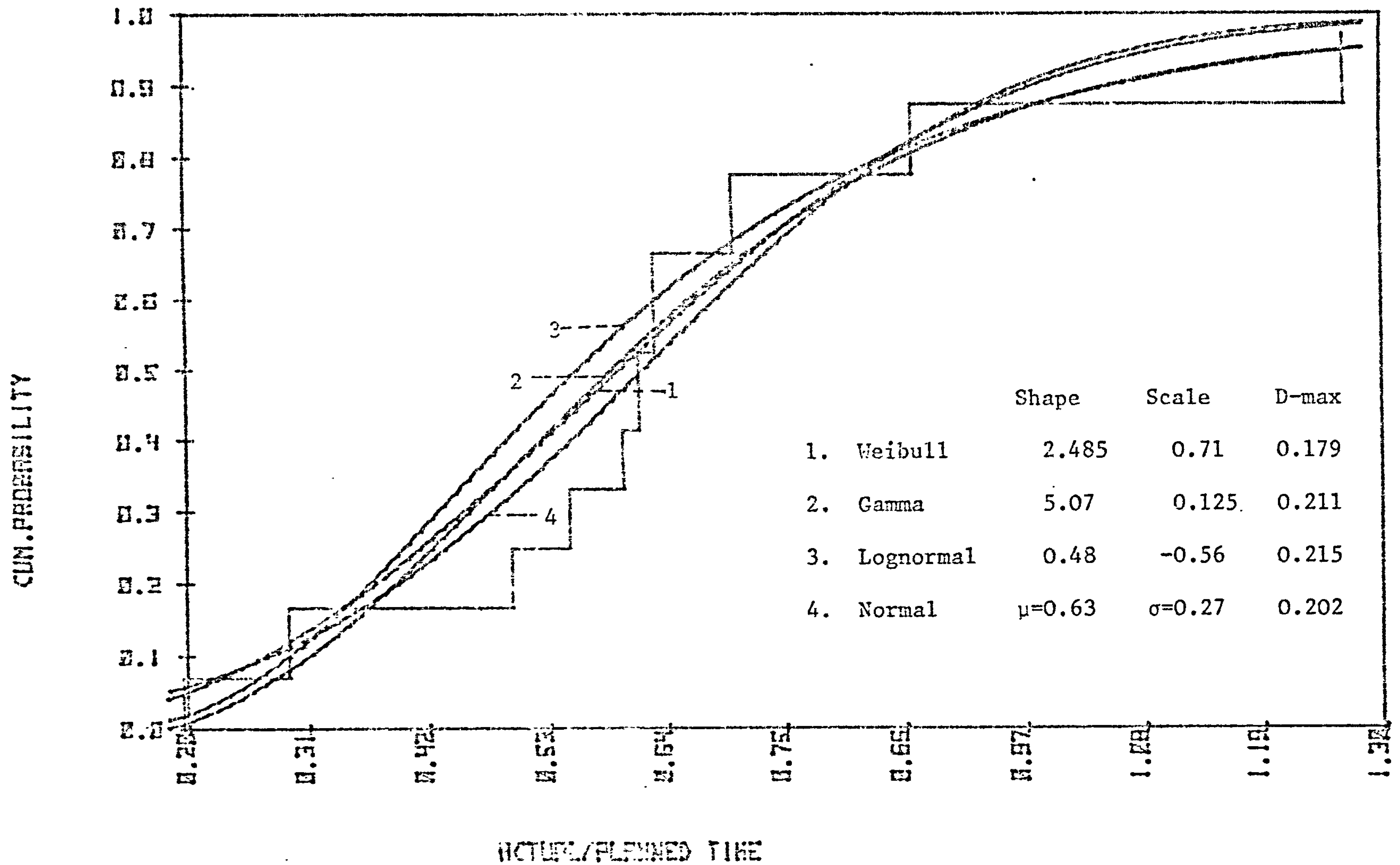


Fig. 5.10 Cumulative Distribution Function Plots of Activity Concrete to Ground Floor Slab for Jacksons

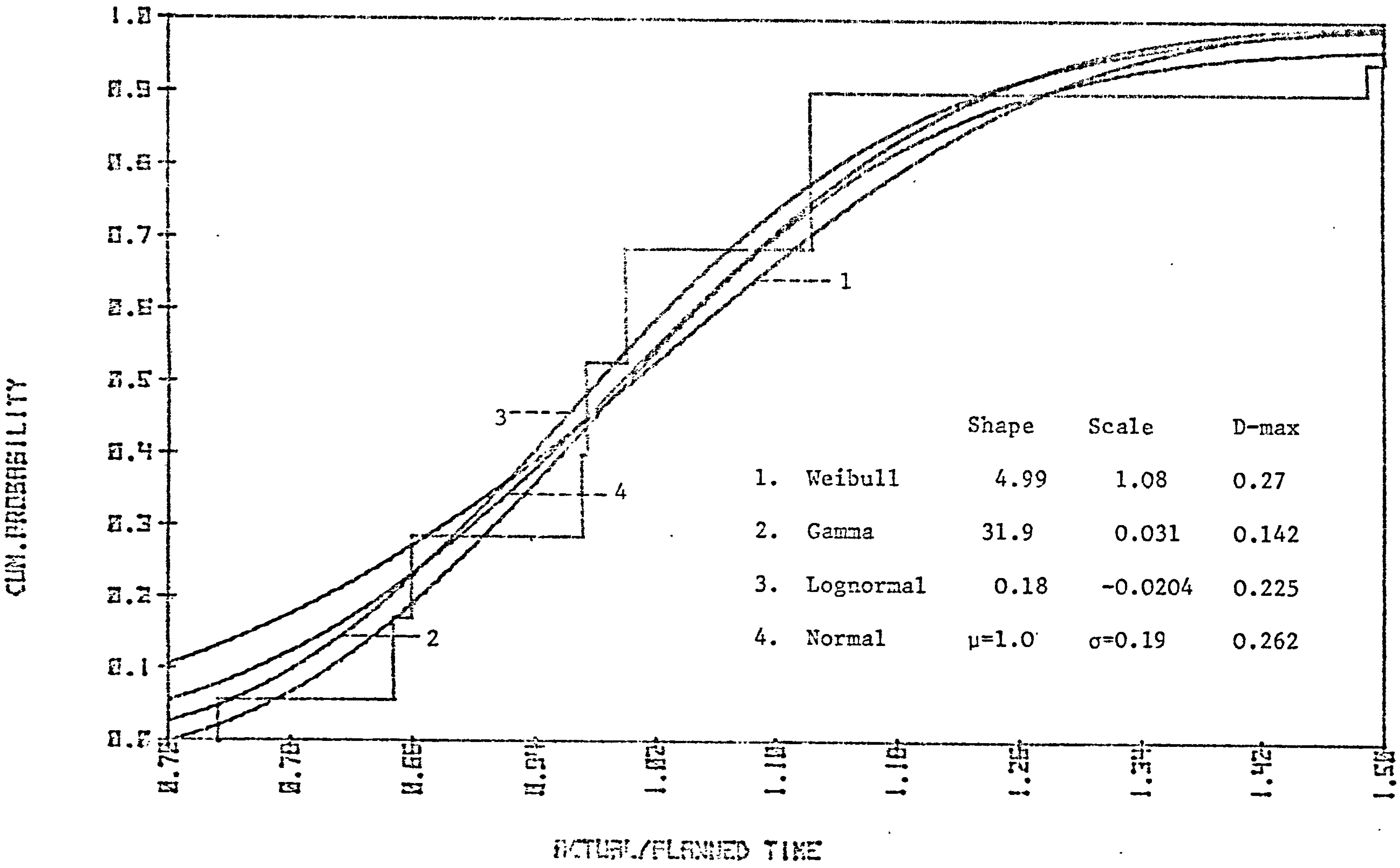


Fig. 5.11 Cumulative Distribution Function Plots of Activity Concrete to Ground Floor Slab for Dernie & Bell

Table 5.13 Comparison of Coodness-of-Fit of the Weibull, Gamma, Lognormal and Normal Distributions

6 Analysis of total actual time taken per bungalow

			Jacksons	Dernie & Bell
Maximum Likelihood Estimates	Weibull	Shape	4.9579	6.5318
		Scale	0.82	0.79
		Mean	0.75	0.73
		Variance	0.0298	0.01719
		D-max	0.198	0.183
	Gamma	Shape	16.2754	29.607
		Scale	0.0457	0.025
		Mean	0.75	0.73
		Variance	0.03	0.02
		D-max	0.281	0.246
	Lognormal	Shape	0.26	0.19
		Scale	-0.3255	-0.3312
		Mean	0.75	0.73
		Variance	0.039	0.01917
		D-max	0.228	0.185
	Normal	Mean	0.7453	0.7302
		Std. Dev.	0.18	0.13
		Variance	0.03318	0.01768
		D-max	0.209	0.186

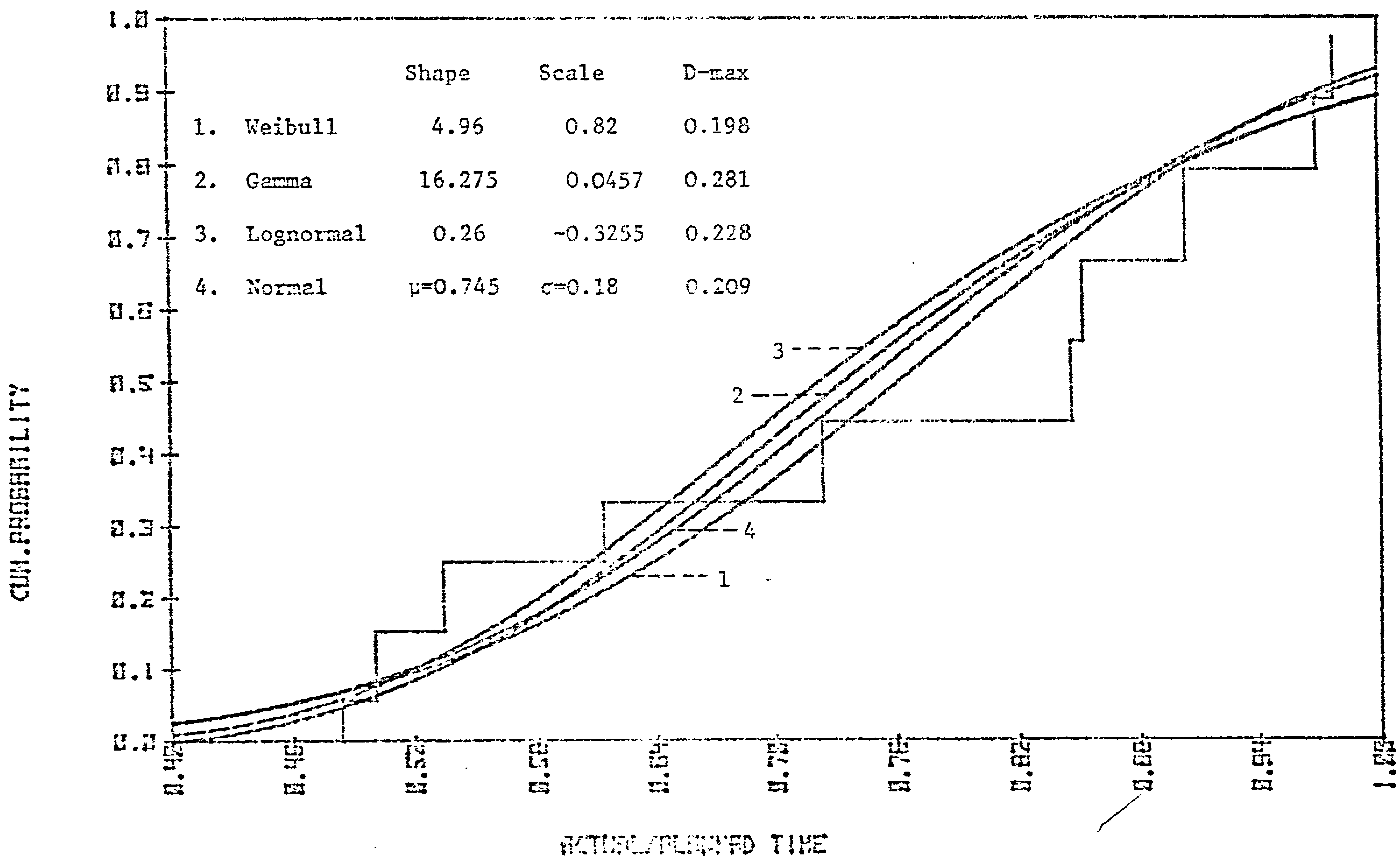


Fig. 5.12 Cumulative Distribution Function Plots of Total Time Taken per Bungalow for Jacksons

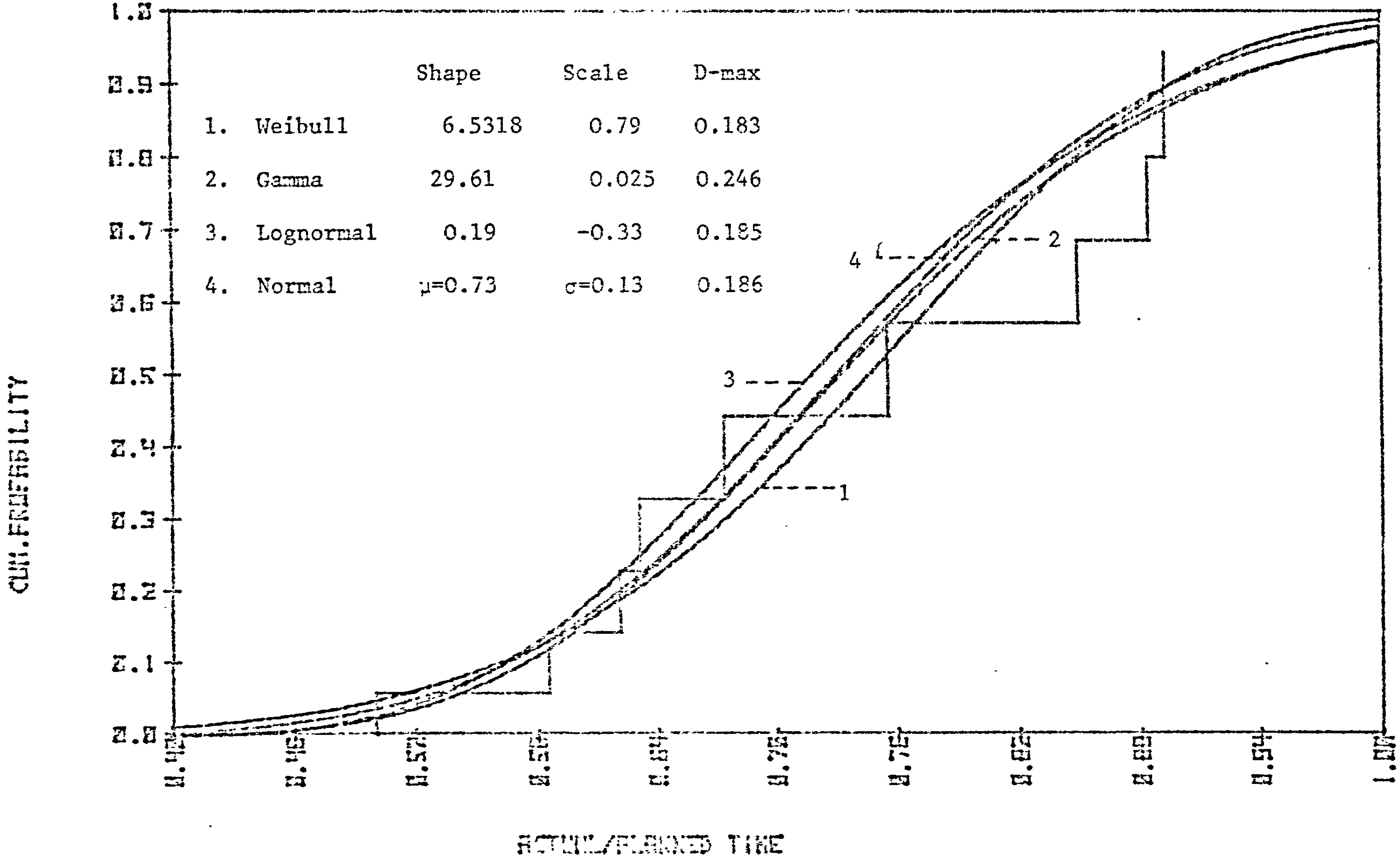


Fig. 5.13 Cumulative Distribution Function Plots of Total Time Taken per Bungalow for Dernie & Bell

5.4 Summary and Conclusions

In this chapter a probabilistic analysis of the ratio of actual and planned time of a housing project is carried out for five major activities of the project. The following distributions were fitted

1. Weibull
2. Gamma
3. Lognormal
4. Normal

A brief introduction to these models is given. Methods of estimation for the parameters of the distributions are discussed. Two most commonly used methods for the goodness-of-fit of a distribution are also described.

Due to its mathematical rigour, maximum likelihood is the most preferred method for the estimation of parameters of a distribution. Maximum likelihood method was used for this purpose. Because all the four candidate distributions are continuous, the Kolomogorov-Smirnov test was utilized for testing the goodness-of-fit of the distributions. Although for most of the activities all the distributions provide a reasonable fit in general the Weibull distribution provides the better fit for the majority of the activities.

Completion time distribution can be used for a number of purposes such as (a) for evaluating performances related to different activities and/or subcontractors. This information is helpful in the estimation, planning, forecasting and control of cost, time and performance (and/or quality) of similar activities for a similar future project.
(b) in preparing a bid price for a project. The bid price may be based on a target time and/or cost corresponding to a specified probability of

completion. This topic needs research in its own merit. Related studies on the topic are reported in Vergara & Boyer (1974), Bor (1977) and Sehgal (1978).

It is stressed that the description of statistical information such as probability distributions, and estimation of statistics such as means and variances can be usefully applied to the quantitative analysis of uncertainty and assessement of associated risk. This information can also be helpful in the formulation of trade-off studies related to the decision making involved in the planning and control of projects.

CHAPTER 6

FORECASTING OF CONSTRUCTION COST INDICES USING BOX-JENKINS METHODOLOGY

In this chapter construction cost indices, their applications, limitations and methods of formation are discussed. Box-Jenkins models are employed to study past behaviour and forecasts future labour, materials and building cost indices.

6.1 Introduction

Cost information is necessarily historical in nature, being collected over a period of years. With the passing of time price levels and market conditions change. Collected information, to be of any use in the cost planning of future projects, must be brought up-to-date and, in some instances, projected into the future to coincide with the planned tender date for a particular project.

To adjust analysed costs, to take account of the passing of time, use can be made of construction costs and tender price indices. In the building industry it has been a common practice to make use of historical indices of construction costs and tender prices. Increasingly these indices are being used to predict future construction costs and tender prices. A number of organisations forecast such indices for their private use and some publish it at regular intervals in various publications. A DHSS research paper (1977) has reviewed 13 of these indices.

Davis, Belfield and Everest, (1975) a chartered quantity firm, who prepare spons Architects and Builders price book reported

"Experience has shown that whatever the difficulties of forecasting, our clients consistently ask for advice on this subject and look to the building profession, in particular the quantity surveryor, to provide the answer."

With the increasing rate of inflation in recent years there has been a greater need for some reasonable indication of future cost levels. Understandably building owners are interested not only in what their financial commitment may be at today's prices but the final cost that they will be called upon to meet and it is invariably to the building profession that they look for the answer.

In view of the increasing use of building cost and tender price indices for predicting future construction cost and tender prices, it was decided to find a suitable and accurate method for forecasting these indices. Most of the organizations predicting these indices use rule of thumb.

In the next few sections of this chapter some basic questions related to types of indices used in the construction industry, need for indices, uses of indices and methods of preparation are considered.

6.1.1 Basic types of indices used in the construction industry

There are two terms which are often confused when considering construction indices. These terms are "tender prices" and "building costs". Building Costs are the cost actually incurred by the builder in the course of his business, i.e. wages, material prices, plant costs, rates and taxes. These factors are themselves, the subject of indices, even down to different types of material, to show their own individual price movement. Tender Price represents the cost a client must pay for a building. They include "building costs" but also take into account market conditions. This means that, for example, in times of boom "tender prices" may increase at a rate greater than "building costs", whilst in a depression the opposite may apply. In exceptional circumstances "tender prices" may actually go down whilst "building costs" are rising.

These two main kinds of indices used in the construction industry are usually formed as follows :

1. Building Cost Indices - various methods are used to compile building cost indices. Some of these are described later in Section 1.4.
2. Tender Price Indices - these are generally compiled by comparing the prices of a proportion of the items within a number of

accepted tenders during a given period against the price of similar items in a base schedule of rates. Each tender is indeed the mean (geometric or arithmetic) of the sample becomes the index for that period.

6.1.2 The need for indices

Government requires indices as a part of the information used in the development of its policies towards an industry for whose products it is a dominant customer. Bryant, C.G.E. (1976) has recognised the need of these indices by government :

"Government needs price indices for several purposes. First, revaluation of expenditure, output and new orders, figures for construction work is essential for the analysis of 'real' developments in the industry. This is necessary to provide an adequate framework for forecasting future developments and in assessing the development of the economy generally. Secondly, price indices compared with indices of contractors' costs provide some indication of the pressure of demand on construction resources; prices rising faster than costs when there is overloading and more slowly when demand is slack. Thirdly, public expenditure programmes may be planned in 'constant' price terms: that is fixed volumes of services to be purchased. Control of expenditure fixed in these terms must be through identifying the money expenditure which is required to purchase the services. Alternatively, an annual 'cash ceiling' may be set for the coming financial year's programme on the basis of forecasts of expenditure prices available at the time. If expenditure prices increase faster than expected, the volume of services purchased is less; if prices rise more slowly, extra services may be purchased. Cash ceilings are set for many construction programmes and the expenditure price level is forecast on the basis of the price levels of tenders already accepted when the limit is set, forecasts of future movements of tender prices and the expected cost of price adjustment clauses where appropriate.

As well as being controlled on an aggregate level, many public sector programmes are also controlled at the project level by cost limits (for example schools, hospitals) : tender prices are used as a basis for adjusting these limits to take account of inflation."

In addition to the Government's need for price indices, price indices are also used for various contract price adjustments. Another important use of a price index is that it is a useful tool to have at one's disposal when considering the problems of assessing or adjusting a cost limit. Mitchel, R. (1971) reported that DOE has for many years been operating methods of cost control over its building activities and an index based on building prices can be a useful indication of a possible need to amend a cost limit from time to time.

6.1.3 Uses of Indices

Building Cost and Tender price indices are used for various purposes, some of these uses are described below :

1. Establishing the level of Individual Tenders

To obtain the level of tenders within a period of time a sample is taken. Each tender is indexed, and the mean (geometric or arithmetic) becomes the index for the period. It is possible to assess each individual tender against the norm, to establish the level of the individual tender as a measure of its effectiveness.

Mitchell, R. (1971) has reported a use of such tender price indices.

"Tenders are sometimes received which show exceedings over the estimate, and the client needs to be advised as to his best course of action. First he will want to know why the price is high. An index of building prices can help here, by measuring the level of pricing offered by the contractor in the tender being examined. This can then be compared with the current national (or specific local) index rating. If the index is below or equal to the average level, this probably means that the job has either been over-designed or that items have been omitted from the estimate. If the index is high, this suggests that factors have been allowed for by the tenderer which were not anticipated by the surveyor in his estimate, and the client must be informed accordingly. This application demonstrates an important use of the information disclosed by an index of this nature, which can greatly improve the service offered to a client by the profession."

2. <u>Adjustment for time</u>

Indices are also used when required to adjust a tender, cost analysis, rate or the like because they are required to relate to a different time period to that for which they were originally compiled.

3. <u>Pricing</u>

Pricing a Bill of Quantities can be done in many ways. One method is to price the scheme at the rates in another project of similar type in a similar location and adjust by means of indices for the difference in time.

4. <u>Cost Planning</u>

In the process of cost planning, cost information that is available concerning previous schemes will be out of date and will have to be updated before use, and this can be done by a price index.

5. <u>Forecasting</u>

Indices can play a major role in forecasting cost trends both to the client and to the Building Contractor. The results of such forecasting can be used as a basis for the calculation of the following :-

a) The value of the return to the contractor under the fluctuations clause of the contract.

b) The cost to the client of a new building at some future time.

c) The likely monthly payments during the course of a building contract.

d) By property owners when reviewing the value for which their property requires to be insured against fire and other perils.

DB & E (1978) and Seely (1976) have demonstrated how to use indices for this purpose.

6. <u>Variation of Price Clauses</u>

A number of indices are published which are used as a basis for the payment of increases or decreases in cost to or from the contractor under the variation of price adjustment clauses of the contract.

Supriyasilp (1975) has used such indices to maximize contractor's [illegible] claiming policies with the forward price adjustment of agreed CPA.

6.1.4 <u>Methods of preparation</u>

A simple index can measure accurately the movement of the price of a single component, but an index measuring the movement of the cost of buildings made up of many componentschanging price independently of each other, is necessarily more complex. Published indices attempt to overcome the problems inherent in calculating a building cost index by adopting a standard approach and adopting it according to the compiler's personal judgement. Two standard approaches are given below :

1. <u>Statistical Method</u>

A typical average building of a particular form of construction is analysed in terms of (1) labour, (2) material, and (3) overheads and profits, and the increase in costs of each of these parts is applied to the analysis. Methods using this approach do not necessarily take account of factors such as bonus payments, productivity, cost of plant, location, the differences between building types, or the state of the market within the industry. Before the resultant figures can be of use for particular projects, adjustment must be made that will take in such factors. Such adjustment will depend on the judgement of the user. This approach is generally called statistical method. Usually building cost indices are formed using this approach.

The DOE index using this statistical approach takes a list of typical materials used in building and their weights and totals the index for each material to arrive at the total materials index. For labour, national figures for earnings in the construction industry, including overtime and bonus payments, and for hours worked are divided one into the other to produce a national index for labour. Overheads and profits are separated, and returns from the Dept. of Trade and Industry census of production and from the Inland Revenue for profit applied to take account of overheads and market conditions.

2. <u>Bill of Quantities Method</u>

A bill of quantities is priced (1) at base year price levels and (2) at the current tender price level, the difference between these two prices providing the means of arriving at a building cost index.

This method can use either

a) The full bill of quantities sent out to tender repriced at base-year level, using a standard schedule of rates, which could be provided by a document such as 'Spons', and the resultant total is compared with the tender received.

b) A full bill of quantities for a typical building priced at base-year rates, and repriced at tender price levels when the tenders are received, using similar or proportionate pricing methods where necessary. The resultant total is then compared with the base-year bill total.

A development of this approach is the recognition that a relatively small number of items in any bill of quantities represents a high proportion of the bill's cost total, and that consideration of the financially significant items only saves a great deal of the time.

Preliminaries often assume particular importance by reflecting the state of the market at tender date, and can be taken into account either by percentage additions or, more accurately, by pricing out in detail, using standard basis for the pricing. Usually tender price indices are formed using this approach.

Indices arrived at by using a method based on tender have the important advantage over indices using other methods in that they have a built-in system of weighting and are reasonably accurate for the particular building type being considered.

Methods can combine the two standard approaches. The Building Cost Index prepared by the Building Cost Information Service (BCIS) is one such. The BCIS attempts to overcome the problem of weighting differences between various forms of building by calculating separate index figures for each type. Weightingsused are decided after analysing bills of quantities for each type of building. Changes in labour and material costs are calculated and applied in a manner similar to the statistical approach, although, the details of the method employed and adjustments made are not defined. The Building Cost Index is intended to provide a guide to the adjustments that should be made to up-date BCIS cost analysis, so it is restricted to BCIS subscribers and is not available to the industry at large.

Davies, Belfield & Everest publish two indices : one for building cost and the other for tender prices using the above approaches.

6.2 Forecasting

6.2.1 Introduction

Forecasting is an important aid in effective and efficient planning and control. The need for forecasting is increasing as management attempts to decrease its dependence on chance and becomes more scientific in dealing with its environment. Since each area of an organisation is related to all others, a good or bad forecast can affect the entire organisation, and the consequences of a bad forecast can be very expensive in social or financial terms. Not surprisingly, therefore, organisations of all kinds now recognise the contribution that accurate and reliable forecasts can make and are devoting much attention to improving their forecasting systems. Without accurate forecasts it is not possible to plan for the efficient use of resources.

A decade ago, a survey of Planning Practices in British Companies was conducted by Hewkin & Kempner (1968). Their investigations on the use of forecasting techniques in marketing show that

"Sophisticated Statistical methods such as regression analysis or Box-Jenkins are hardly ever used; few managers use even relatively simple techniques such as exponential smoothing".

State of the art doesn't seem much different in other areas even today. Makridakis & Wheelwright (1978) have rightly commented

"As with the development of most management science techniques, the application of forecasting methodologies has lagged behind their theoretical formulation and verification. Although many managers and students are aware of the need for improved forecasting, few are familiar with the full range of existing techniques and their characteristics and few have the knowledge required to select and successfully apply the most appropriate methods in a specific situation".

M. F. Green (1978) has emphasised the need for a stochastic forecasting technique for the forecast of building cost and tender prices. He has suggested that sophisticated analytical methods should be adopted which allow the full complexity of the problem to be modelled, yet simplify the value judgements which must be made.

6.2.2 Criteria for the Comparison and Selection of Forecasting Methods

The fundamental importance of forecasting as the cornerstone of planning and control at all levels of an organisation makes it essential to use a sound procedure for obtaining the necessary forecasts. A planning system can only be as good as the forecasting procedure on which it is based. Many forecasting techniques have been developed in recent years to handle the increasing variety and complexity of forecasting problems. Each has its own characteristics, uses, drawbacks, limitations and scope. Care should be taken to choose a correct technique for a particular application. The election of a forecasting method depends on many factors such as the pattern of the data, the relevance and availability of historical data, the degree of accuracy desirable, the time horizon to be covered in forecasting, the cost/benefit (or value) of the forecast to the organization, the time available for making the analysis, and the ease of application in organization situation. The assignments of priorities to them in comparing and selecting a forecasting method for a given situation will depend in part on the organization's experience with forecasting. Most of the analyses and empirical research reported in the literature indicate that selection of an appropriate technique is usually done on the basis of accuracy. To select an accurate method, a general introduction to different forecasting techniques, their characteristics, uses and limitations are discussed in Appendix D.

6.2.3 Building Cost and Tender Price Indices

The two principal factors affecting building costs are materials and labour costs. The likely fluctuations of these factors cannot be predicted with absolute certainty, since both materials and labour costs are influenced by factors such as international economic trend, national economic policies, market conditions and inflation. As described in section 1, there are various methods of formation of building cost indices. Mitchell (1971), Seeley (1976) and Bathurst & Butler (1973) have discussed some of these methods. Without entering into a discussion as to details of the methods of formation of building costs and tender price indices it is clear that there are many uncertainties involved. DB & E have identified what they believe to be the important factors. The purpose of the present research was to develop quantitative models to describe the behaviour of basic building cost fluctuations, tender prices and their major determinants, the labour and materials prices. It was decided to investigate the problem from purely statistical and mathematical points of view using established methods of forecasting.

The DB & E indices of building costs are formed by assessing the labour costs from a contract wages sheet taking into account each change and each **prospective** change; to this is added the relative cost of materials using the department of trade and industry's indices. For the forecasts of materials prices DB & E simply make an assessment of the anticipated rate of inflation over the next two years. DB & E forecast their Building Cost Index as a single number, and tender price index in a range of minimum and maximum values. No range is given for building cost index and no likely value for tender price index. The best method would be to forecast a most likely value and to specify its accuracy so that, the risks associated with decisions based upon the forecasts may be calculated. The accuracy of the forecasts may be expressed by calculating probability limits on either side of the forecast. These limits may be calculated for any convenient set of probabilities, for example 50 or 95%. They are such that the realised value of the forecasts, when it eventually occurs will be included within these limits with the stated probability.

The data for the labour, materials, building cost and tender price indices were provided by DB & E. These indices have been transformed to a common base year, 1970, and are presented in tables 6.2, 6.6, 6.10, 6.14.

6.2.4 Selection of Box-Jenkins Methodology

Autoregressive/Moving Average (ARMA) models have been studied extensively by George Box and Gwilym Jenkins (1970), and their names frequently have been used synonymously with general ARMA processes applied to time-series analysis, forecasting and control.

The Box-Jenkins method is one of the many procedures for short term forecasting. Most methods currently in use, utilize information from past values. Other such methods are described for example by Winters (1960), Brown (1963), I.C.I. (1964), Harrison (1965), Wheelwright & Makridakis (1973). The more important of these univariate forecasting techniques have been compared by Reid (1969, 1971) on economic time series when more than 50 observations are available. Reid found that the Box-Jenkins method gave the "best" one-step ahead forecasts for most time series. Granger and Newbold (1974) have examined more than 100 macroeconomic series and show that Box-Jenkins give better forecasts than Holt-Winters and step-wise autoregression. Forecasts of four economic variables made using the Box-Jenkins approach were compared with forecasting model by Naylor, T. H., et al (1972). In each case it was found that the Box-Jenkins relationship produced substantially smaller forecast errors. In view of these evidences of higher forecasting accuracy, and of the fact that many exponential smoothing models are subsets of the general class of Box-Jenkins models, it was decided to use Box-Jenkins methodology for our investigation.

6.2.5 Box-Jenkins Method

The first step in dealing with a set of data is to decide the pattern that will best fit it. One of the major advantages of the Box-Jenkins method, unlike all other forecasting methods, is that it assumes no fixed pattern initially. The form of the eventual forecast function is dictated, to a large extent, by the data - a principle known as "letting the data speak for itself". Professor Jenkins (1979) has found the following guidelines very useful for tackling problems associated with business forecasting :

1. Analyse decision taking system served by forecasts
2. Define forecasts needed to serve decision taking system
3. Develop conceptual model describing mechanisms influencing forecasts
4. Define data available and not available
5. Develop method for generating forecasts
6. Conduct experiments to assess accuracy of forecasts
7. Determine how judgements are to be incorporated into forecasts
8. Implement forecasting system
9. Appraise retrospectively its effectiveness

Professor Jenkins (1979) has provided some guidelines given below for building models for forecasting, planning and control on the basis of his wide experience in the field.

1. Understand the problem and the purpose of building the model.
2. Understand the decision-taking system which the model will serve.
3. Work out early on how the model is to be implemented.

4. Structure the quantitative model by building a conceptual model of the appropriate environmental system, displaying the mechanisms involved.
5. Select the data carefully, understand its limitations and plot it in a variety of ways.
6. Aim for simple models, involving few variables, first and then elaborate later, if necessary.
7. Proceed iteratively via
   - Identification (Specification)
   - Estimation (Fitting)
   - Checking (Criticism)
8. Aim for parsimony in parameterisation - avoid over parameterisation.
9. Understand what the model has to say about the data.
10. Conduct experiments with the model (simulations) to understand its limitations.
11. Present the results from the model in simple terms to those who have to use it.

The main technical stages in setting up a Box-Jenkins forecasting model as described by Jenkins (1979) are as follows :

a) Identification (or Specification) of forecasting model involves the use of rough data analysis tools (range-mean plots, correlation and partial correlation functions), to arrive at initial guesses of the data transformation, degrees of differencing needed to induce stationarity and the degrees of the polynomials appearing in the various autoregressive and moving average operators appearing in the model.

b) Estimation (or fitting) involves using fully efficient (likelihood) methods for estimating the parameters, their standard errors and correlations, and the residual variances and covariances.

c) Diagnostic Checking (or criticism) Since no model can ever be 'correct', checking is an important step which involves looking for model inadequacies or for areas where simplification can take place. The most important model criticism criteria are :

- the residuals left unexplained by the model - are the any abnormally large residuals which can be linked to known external factors or other explanatory variables ?
- the residual correlations and partial correlations - do they provide evidence that the model can be elaborated in a particular direction ?

When forecasts are needed, the fitted model is used to generate optimal forecasts by simple recursive calculation. In particular, this model completely determines whether the forecast projections should follow a straight line, an exponential curve, and so on. In addition the fitted model allows to see exactly how the forecasts utilize past data, to determine the variance of the forecast errors, and to calculate limits within which a future value of the series will lie with a given probability.

d) Consider alternative models if necessary

If the first model appears to be inadequate for some reasons, then other ARIMA models may be studied by repeating for the above procedure, until a 'satisfactory' model is found.

Computer programs

The application of Box-Jenkins method depends on the availability of a good suite of computer programs. Computer programs for time series analysis using Box-Jenkins method are commercially available. In this study an I.C.L. package of three computer programs for Time Series Analysis Forecasting and Control, at Bradford University has been used.

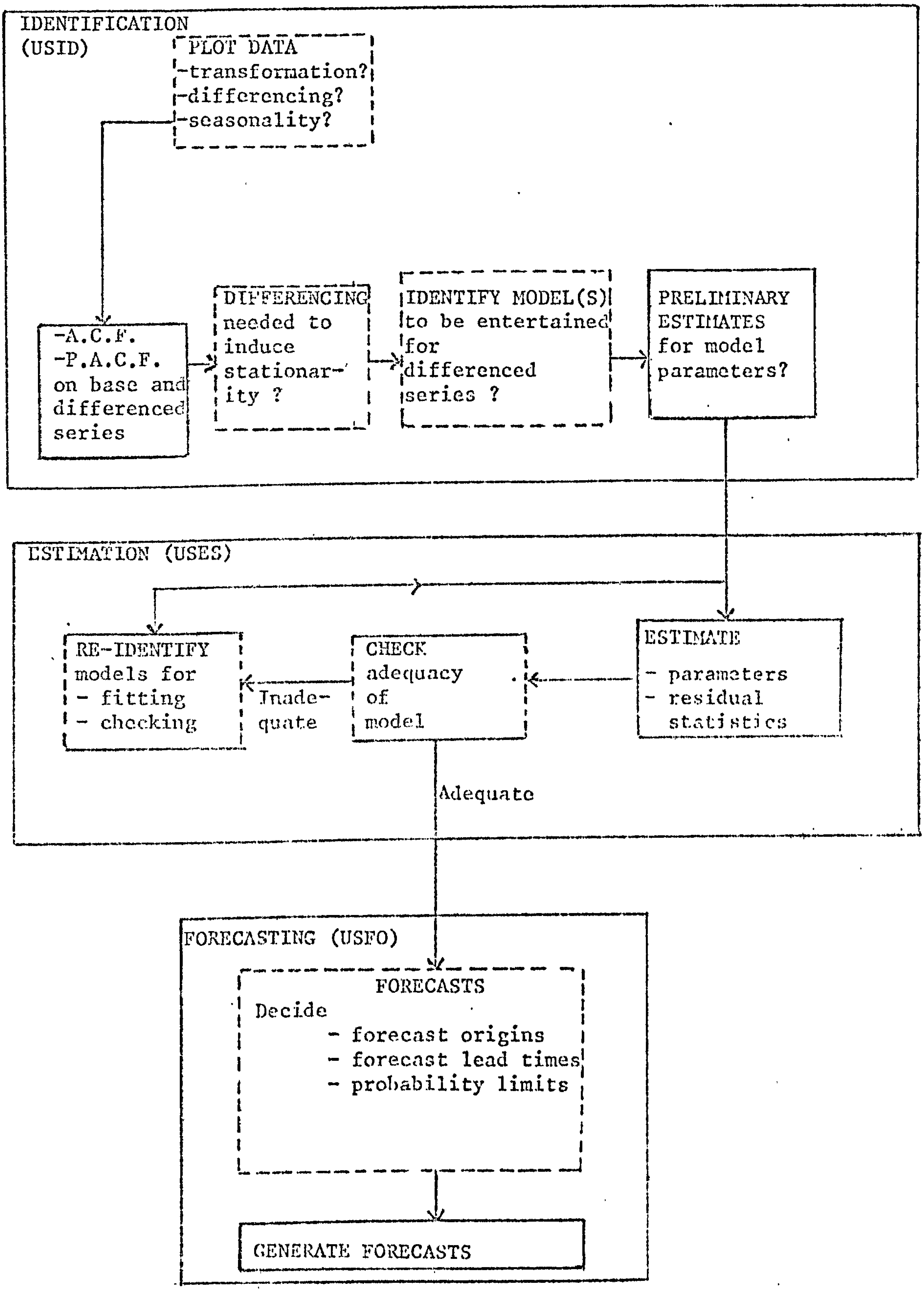


Fig 6.1 Flow diagram for Box-Jenkins three computer programs

Fig. 6.1 shows a flow diagram for univariate stochastic model building and forecasting, based on three computer programs : USID (Univariate Stochastic Identification Program), USES (Univariate Stochastic Estimation Program), USFO (Univariate Stochastic Forecasting Program).

6.2.6 Class of Box-Jenkins Models Available

6.2.6.1 Stationary Models. If a time series is stationary, that is, it is in statistical equilibrium about a constant mean c, it can be represented by a wide class of models, line or in the transformed variable, called autoregressive-moving average (ARMA) models, that is

$$(Z_t^* - c) = \emptyset_1 \; (Z_{t-1}^* - c) \; ..... \; -\emptyset_p (Z_{t-p}^* - c)$$

$$+ \; a_t - \theta_1 \; a_{t-1} \; ..... \; -\theta_q \; a_{t-q} \qquad (1)$$

where $Z_t^* = Z_t^{(\lambda)}$

In words, the model represents the current value of the transformed series as a linear function of :

(a) past values of the transformed series $Z_t^{(\lambda)}$,

(b) current and past values of the residuals a_t

(which may be thought of as the one-step-ahead forecast errors of $Z_t^{(\lambda)}$)

Alternatively, introducing the backward shift operator

$B \; Z_t^* = Z_{t-1}^*$, $B^j \; Z_t^* = Z_{t-j}^*$,

$B \; a_t = a_{t-1}$, $B^j \; a_t = a_{t-j}$

The ARMA model may be written in operator form as

$$Z_t^{(\lambda)} - c = \frac{\theta(B)}{\emptyset(B)} = \frac{1-\theta_1 B \; ..... \; \theta_q B^q}{1-\emptyset_1 B \; ..... \; \emptyset_p B^p} \quad a_t \qquad (2)$$

The parameters in (2) need to satisfy the following conditions :

(a) the roots (factors) of $\phi(B)=0$ lie outside (inside) the unit circle for the autoregressive operators $\phi(B)$ to be stationary (series is in statistical equilibrium about a fixed mean),

(b) the roots (factors) of $\theta(B)=0$ lie outside (inside) the unit circle for the moving average operators $\theta(B)$ to be invertible (weights applied to past history of series to generate forecasts die out).

The model (2) represents the transformed series $Z_t^{(\lambda)}$ as the output from a linear fitter whose input is a random series with zero mean and constant variance ('white noise') and whose filter transfer function is a ratio of two polynomials in the backward shift operator B. Writing the model in the form (2), and factorising the polynomials in B, greatly helps in understanding the mechanism generating the series.

To achieve parsimony in parameterisation, that is a representation which economises in the use of parameters, it is necessary in general to include both autoregressive and moving average terms in the model. In contrast, the use of an autoregressive model to represent a series which is described by a moving average model, or vice versa, will result in the wasteful use of parameters.

6.2.6.2 Non-Stationary Models. Many empirical time series behave as though they had no fixed mean. Even so, they exhibit homogeneity in the sense that, apart from local level, or perhaps local level and trend, one part of the series behaves much like any other part. Such a class of models, is obtained by first differencing the transformed series of time to induce stationarity, that is

$$w_t = \nabla^d Z_t^{(\lambda)} \qquad (3a)$$

The stationary series w_t can then be represented by an ARMA model

$$w_t - c = \frac{\theta(B)}{\phi(B)} a_t = \frac{1-\theta_1 B- \ldots\ldots -\theta_q B^q}{1-\phi_1 B- \ldots\ldots -\phi_p B^p} a_t \qquad (3b)$$

The model defined by (3a) and (3b) is called an Autoregressive Integrated Moving Average model or ARIMA (p,d,q) model.

Thus, models involving single differencing ∇ can be used to describe series whose level is continuously updated by random shocks; models involving double differencing ∇^2 can describe series whose level and slope are continously updated by random shocks, and so on. Usually, single differencing is adequate to describe most non-stationary series but occasionally double differencing may be necessary.

6.2.6.3 Seasonal Models. To describe series containing seasonal patterns with period s, and which may also be evolving in nonstationary manner, a new class of models has been developed. Thus, the seasonal $(p,d,q) \times (P,D,Q)_s$ model is defined by

$$w_t = \nabla^d \nabla_s^D z_t^{(\lambda)},$$

$$w_t - c = \frac{\theta(B)\ \Theta(B^s)}{\phi(B)\ \Phi(B^s)} a_t \qquad (4)$$

where $\phi(B)$, $\theta(B)$ are non-seasonal autoregressive and moving average operators, as defined in (2).

$$\nabla_s z_t^{(\lambda)} = z_t^{(\lambda)} - z_{t-s}^{(\lambda)}$$

is the seasonal differencing operator, and

$$\Phi(B^s) = 1 - \Phi_1 B^s - \Phi_2 B^{2s} \ldots\ldots \Phi_p^{p_s},$$

$$\Theta(B^s) = 1 - \Theta_1 B^s - \Theta_2 B^{2s} \ldots\ldots \Theta_Q B^{Qs},$$

are seasonal autoregressive and moving average operators. The seasonal model (4) is capable of representing a wide class of stochastic trends and stochastic seasonal patterns, such as occur in practice, under the umbrella of one single model.

In addition, the constant c, which measures the mean of the appropriately transformed and differenced series w_t, can be used to describe a wide class of deterministic functions of time, should prior knowledge, or the model building process, suggest that they be included.

If necessary, the model (4), which is multiplicative respect to its non-seasonal and seasonal components, may be replaced by a non-multiplicative model if there are indications that this elaboration is necessary at the identification stage of model building (Box-Jenkins, 1970). Furthermore, in some cases it may be necessary to include several seasonal periods. For example, energy data may display a cycle over a day, a further cycle over a week and yet a further cycle over a year. Such multiple seasonality can be described by elaborating (4) so as to include further stages of seasonal differencing and further seasonal autoregressive and moving average operators.

The most important technicalaspect in Box-Jenkins methodology is the identification of a suitable model from a wide class of models available. This aspect is discussed in more detail in the next section. Once a suitable model is identified then it is fairly easy to estimate the parameters of the models and to make forecasts using computer programs developed for this purpose.

6.2.7 Identification process for Box-Jenkins models

Eq (4) supplies too rich a class of models to permit immediate estimation. Therefore using experience and the data, first identify a sub-class of models worthy to be entertained.

The primary data-analysis tools such as mean range plots are used to get a guidance for a suitable transformation, then autocovariance, autocorrelation and partial autocorrelation functions are used to find the degree of differencing necessary to induce stationarity.

Values to be entertained for p and q may usually be deduced by inspecting the sample autocorrelation and partial autocorrelations using knowledge of the behaviours of the theoretical autocorrelation functions for various types of models. The characteristics of theoretical autocorrelations $\rho_k(w)$ for models of order (1,d,0), (2,d,0), (0,d,1), (0,d,2), and (1,d,1) are shown in table 6.1.

Of considerable help in judging the reality of sample autocorrelations is the following approximate formula due to Bartlett for the standard error (S.E.) of r_k, namely

$$\text{S.E. } [r_k] \simeq \sqrt{\left\{\frac{1}{n}\left(1 + 2\rho_1^{\,2} + 2\rho_2^{\,2} + \ldots\ldots\right)\right\}} \qquad (5)$$

Since we do not know the theoretical autocorrelations ρ_k, they have to be replaced by their sample estimates r_k.

By substituting sample estimates for ρ_k in table 6.1, preliminary values for the model parameters may be obtained.

In practice, the autos and partials do not always behave according to clear pattern because of randomness in the data. The behaviour of autos and partials indicated in the previous section is theoretical and assumes no noise. When there is noise; the autos or partials may be higher or lower than their theoretical value. Since the amount of

Behaviour of the autocorrelation functions of an ARIMA (p,d,q) model

Order	(1,d,0)	(0,d,1)
Behaviour of ρ_k	decays exponentially	only ρ_1 nonzero
Behaviour of ϕ_{kk}	only ϕ_{11} nonzero	exponential dominates decay
Preliminary estimates from	$\phi_1 = \rho_1$	$\rho_1 = \frac{-\theta_1}{1+\theta_1^2}$
Admissible region	$-1 < \phi_1 < 1$	$-1 < \theta_1 < 1$
Order	**(2,d,0)**	**(0,d,2)**
Behaviour of ρ_k	mixture of exponentials or damped sine wave	only ρ_1 and ρ_2 nonzero
Behaviour of ϕ_{kk}	only ϕ_{11} and ϕ_{22} nonzero	dominated by mixture of exponentials or damped sine wave
Preliminary estimates from	$\phi_1 = \frac{\rho_1(1-\rho_2)}{1-\rho_1^2}$ $\theta_2 = \frac{\rho_2-\rho_1^2}{1-\rho_1^2}$	$\rho_1 = \frac{-\theta_1(1-\theta_2)}{1+\theta_1^2+\theta_2^2}$ $\rho_2 = \frac{-\theta_2}{1+\theta_1^2+\theta_2^2}$
Admissible region	$-1 < \phi_2 < 1$ $\phi_2 + \phi_1 < 1$ $\phi_2 - \phi_1 < 1$	$-1 < \theta_2 < 1$ $\theta_2 + \theta_1 < 1$ $\theta_2 - \theta_1 < 1$
Order	**(1,d,1)**	
Behaviour of ρ_k	decays exponentially from first lag	
Behaviour of ϕ_{kk}	dominated by exponential decay from first lag	
Preliminary estimates from	$\rho_1 = \frac{(1-\theta_1\phi_1)(\phi_1-\theta_1)}{1+\theta_1^2-2\phi_1\theta_1}$, $\rho_2 = \rho_1\phi_1$	
Admissible region	$-1 < \phi_1 < 1$	$-1 < \theta_1 < 1$

Table 6.1

variation caused by randomness is not known, the pattern in the autos and partials is used to infer a "tentative" ARIMA model.

It is known that the autos and partials are normally distributed with mean zero and standard error $1/\sqrt{n}$. Based on this knowledge, confidence intervals can be constructed and used to determine the chances that a given auto or partial will be significantly different from zero. A 95% confidence interval will require an auto or partial to be more than about $2/\sqrt{n}$ in order to be significant. This can be used as a rough rule to determine the true behaviour of the auto and partial correlations.

A three-step procedure for identification described by Wheelright and Makridakis can be summarized :

1. Obtaining a stationary series. If the time series is not stationary, spurious autocorrelations will result that will hinder the model identification procedure. Therefore, if the series is not stationary, it must be transformed to a stationery series by taking the appropriate level of differences.

2. Examining the autocorrelations and partial autocorrelations. (prferably in graphic form). One must identify the correlations that drop off exponentially (i.e. trail off) to zero. If this trailing off happens among the autocorrelation coefficients, an AR process is implied; if it happens among the partial autocorrelations, an MA process is implied; and if both drop off exponentially, a mixed ARMA process is indicated.

3. Examining the remaining corrélations (those do not drop off to zero) to determine the order of the AR or MA process. This determination is made by counting the number of autocorrelations or partial autocorrelations significantly different from zero. For a mixed ARMA

process, the AR order is determined from the partials and the MA order is determined from the autos.

6.3 Analysis of the Data and Results

1. Introduction

Data for Building Cost, labour and materials indices for 1971-79 were provided by D B & E. The quarterly Building Cost indices for 1966-78 were also supplied by them. All the four indices have been transformed to base 1970=100 and are presented in table 6.2, 6.6, 6.10, and 6.14 respectively.

Building Cost indices, labour indices and materials indices series comprising of monthly indices for 1971-79, and quarterly Building Cost indices, have been analysed separately. The usual steps of identification, estimation, forecasting and checking were performed using the three programs : Univariate Stochastic Identification (USID), Univariate Stochastic Estimation (USES), and Univariate Stochastic Forecasting (USFO) of ICL's package for Box-Jenkins time series analysis, forecasting and control.

6.3.1 Building Cost Indices

6.3.1.1 Identification

There is an obvious trend in the building cost indices 1971-79 series shown in fig. 6.2. The range mean plot in fig. 6.3(a) suggests that logarithmic transformation would be suitable. The Logarithmic transformed series is given in fig. 6.4 and the corresponding range-mean plot in fig. 6.3(b). Autocorrelations and partial autocorrelations of the transformed series are given in table 6.3 and are shown in fig. 6.5. Autocorrelations are quite significant and are not dying out. Also chi-squared statistic is quite large suggesting that series is non-stationary. So differencing is necessary to achieve the stationarity. First difference of the transformed series is taken. The first differenced transformed series is shown in fig. 6.6. The mean and variance of the differenced transformed series are mean = 0.0118768

variance = 0.0003037

The Autocorrelations and partial autocorrelations of the transformed series are given in table 6.4 and shown in fig. 6.7. The autos and partials are not significant. Chi-squared statistics also support this, suggesting that series is stationary about the mean, and consist of white noise only. Thus an ARIMA (0,1,0) model is identified.

6.3.1.2 Estimation

A constant term for forecasting was estimated using the program USES.

constant term = 0.0118769

S.D. constant term = 0.001685

Estimated Residual Variance = 0.0003037

Mean of the residual series = -0.363378E-8

variance of residual series = 0.3037E-3

variance ratio, Residual/derived = 1.0

Approximate Standard error = 0.097

χ^2 - Statistic = 6.04 with 11 degrees of freedom.

Autocorrelations of the residual series are given below

lag	Autos	lag	Autos
0	1.0		
1	0.024	7	-0.131
2	-0.026	8	0.024
3	-0.025	9	-0.038
4	-0.072	10	0.032
5	0.004	11	-0.026
6	-0.022	12	0.167

6.3.1.3 Forecasts

Forecasts were made from the identified (0,1,0) ARIMA model for the next 24 months ie 1980 and 81 from December 1979 as base. The identified model was tested for the 12 months of 1979, Lower and upper 50% probability limits were also calculated for each forecast. The forecasts are shown in table 6.5 and fig. 6.8. Diagnostic checks were carried out for the model.

For the purpose of comparison, forecasts from the above model have been presented in a compact form, giving actual values as were available and DB & E forecasts.

6.3.2 Labour Indices

6.3.2.1 Identification

There is an obvious trend in the labour indices 1971-79 series shown in fig. 6.9. The range-mean plot in fig 6.10(a) suggests that logarithmic transformation would be suitable. The logarithmic transformed series is given in fig 6.11 and the corresponding range-mean plot in fig. 6.10(b).

Autocorrelation and partial autocorrelations of the transformed series are given in table 6.7 and are shown in fig. 6.12.

respectively. Autocorrelations are quite significant and are not dying out. Also chi-squared statistic is quite large suggesting that series is non-stationary. So differencing is necessary to achieve stationarity. First difference of the transformed series is taken and is shown in fig. 6.13 The mean and variance of the differenced transformed series are

mean = 0.0111219

variance = 0.001079

The Autocorrelations and partial autocorrelations of the series are given in table 6.8 and shown in figs 6.14. The autos and partial are not significant. Chi -squared statistic also supports this, suggesting that series is stationary about the mean, and consists of white noise only. Thus an ARIMA (0,1,0) model is identified.

6.3.2.2 Estimation Labour Indices

A constant term for forecasting was estimated using the program USES.

constant term = 0.0111219

S.D. constant term = 0.003179

Estimated Residual variance = 0.001079

Mean of the residual series = 0.1037E-8

variance.residual series = 0.001079

variance ratio, Residual/derived = 1.0

Approximate standard error = 0.097

χ^2-Statistics = 4.81 with 11 degrees of freedom

Autocorrelations of the residual series are given below

lag	Autos	lag	Autos
0	1.0		
1	-0.039	7	-0.081
2	-0.05	8	0.012
3	-0.025	9	-0.071
4	-0.11	10	0.013
5	0.022	11	0.087
6	-0.09	12	-0.004

6.3.2.3 Forecasts Labour Indices

Forecasts were made from the identified (0,1,0) ARIMA model for the next 24 months i.e. for 1980 and 1981 from December 1979 as base point. The identified model was tested for the 12 months of 1979. Lower and upper 50% probability limits were also calculated for each forecast. The forecasts are shown in table 6.9 and fig 6.15

Diagnostic checks were carried out for the model.

For the purpose of comparison, forecasts from the above model have been presented in a compact form, giving actual values as were available and DB & E forecasts.

6.3.3 Materials Indices

6.3.3.1 Identification

There is an obvious trend in the materials indices 1971-79 series shown in fig 6.16. The range-mean plot in fig 6.17(a) suggests that logarithmic transformation would be suitable. The logarithmic transformed series is given in fig 6.18, and the corresponding range-mean plot in fig. 6.17(b)

Autocorrelations and partial autocorrelations of the transformed series are given in table 6.11 and are shown in fig. 6.19 respectively. Autocorrelations are quite significant and are not dying out. Also Chi-squared statistic is quite large suggesting that series is non-stationary. So differencing is necessary to achieve stationarity. First difference of the transformed series is taken and is shown in fig 6.20. The mean and variance of the first differenced transformed series are

mean = 0.0126

variance = 0.000079286

The autocorrelations and partial autocorrelations of the series are given in table 6.12 and shown in fig . 6.21. First four autocorrelations are significant, rest are not significant, while one partial autocorrelation is significant. Chi-squared statistic is significant. Partial autocorrelation suggests ARIMA (1,1,0) model.

6.3.3.2 Estimation Materials Indices

Autoregressive Operator ϕ and constant term for forecasting were estimated using the program USES.

ϕ = 0.511175, S.D.ϕ = 0.082929

constant term = 0.0125495

S.D. constant term = 0.0014997

sum of squares = 0.0062734

Estimated Residual variance = 0.00005863

Mean of the residual series = 0.0000355493

variance residual series = 0.000058585

variance ratio, Residual/derived = 1.0

Approximate standard error $1/\sqrt{n}$ = 0.097

Chi-squared statistic = 11.4 with 10 degrees of freedom.

Autocorrelations of the residual series are given below

lag	Auto	lag	Auto
0	1.0		
1	-0.096	7	0.05
2	0.057	8	-0.001
3	0.24	9	0.096
4	0.016	10	0.001
5	-0.053	11	0.118
6	0.056	12	0.07

6.3.3.3 Forecasts Materials Indices

Forecasts were made from the identified (1,1,0) ARIMA model for the next 24 months i.e. for 1980 and 1981 from December 1979 as base point. The identified model was tested for the 12 months of 1979. Lower and upper 50% probability limits were also calculated for each forecast. The forecasts are shown in table 6.13 and fig. 6.22.

Diagnostic checks were carried out for the model.

For the purpose of comparison, forecasts from the above model have been presented in a compact form, giving actual values as were available and D B & E forecasts.

6.3.4 Quarterly Building Cost Indices

6.3.4.1 Identification

There is an obvious trend in the Quarterly building cost indices 1966-69 series shown in fig. 6.23. The range-mean plot in fig. 6.24(a) suggests that logarithmic transformation would be suitable. The logarithmic transformed series is given infig 6.25 and the corresponding range-mean plot in fig. 6.24(b).

Autocorrelations and partial autocorrelations of the transformed series are given in table 6.15 and are shown in fig. 6.26. respectively. Autocorrelations are quite significant and are not dying out. Also Chi-squared statistic is quite large suggesting that series is non-stationary. So differencing is necessary to achieve stationarity. First difference of the transformed series is taken and is shown in fig 6.27 The mean and variance of the first differenced transformed series are

mean = 0.02861

variance = 0.0093851

The autocorrelations and partial autocorrelations of the series are given in table 6.16 and shown in fig..6.28. First autocorrelations and partial autocorrelations are significant. Chi-squared statistic is significant. Autos and partials suggests the suitability of ARIMA (1,1,0) model.

6.3.4.2 <u>Estimation</u> <u>Quarterly Building Cost Indices</u>

Autoregressive Operator and constant term for forecasting were estimated using the program USES.

ϕ = 0.223874

S.D. = 0.1313

constant term = 0.0285478

S.D. constant term = 0.00391198

sum of squares = 0.02817791

overall constant term (for forecasting) = 0.0221567

Estimated residual variance = 0.000512326

mean of the residual series = 0.000039096

variance residual series = 0.00051227

variance ratio, Residual/Derived = 0.9499

Approximate standard error = 0.135

Chi-squared statistic ≐ 4.3 with 2 degrees of freedom

Autocorrelations of the residuals series are

given below

lag	Auto
1	-0.003
2	-0.02
3	0.061
4	0.272

6.3.4.3 Forecasting Quarterly Building Cost Indices

Forecasts were made from the identified (1,1,0) ARIMA model for the next 12 quarters, i.e. for 1980-82 from last quarter of 1979 as base point. The identified model was tested for the last 8 quarters i.e. for 1978 and 79. Lower and upper 50% probability forecasts were also calculated for each forecast. The forecasts shown in table 6.17 and fig 6.29.

Diagnostic checks were carried out for the model. For the purpose of comparison, forecasts from the above model have been presented in a compact form, giving actual values as were available and DB & E forecasts.

Year \ Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1971	104.0	105.0	105.0	107.0	108.0	110.0	110.6	110.6	111.0	111.3	111.3	111.3
1972	111.3	111.3	112.0	112.0	112.0	113.0	113.0	114.0	130.0	131.0	132.0	133.0
1973	134.0	134.0	135.0	135.0	136.0	137.0	142.0	143.0	144.0	145.0	146.0	147.0
1974	151.0	153.7	156.0	159.0	160.5	168.4	170.0	171.5	173.5	174.1	175.6	178.2
1975	180.9	192.0	195.0	198.0	198.9	199.5	213.0	215.5	216.0	216.8	218.0	219.6
1976	222.1	224.5	225.9	229.2	232.9	235.2	248.5	251.0	253.0	255.0	258.0	259.2
1977	261.9	262.4	265.8	269.1	271.0	272.5	279.7	280.7	280.7	281.9	282.5	282.7
1978	284.0	284.0	284.0	288.8	288.8	288.8	306.2	306.2	306.2	311.3	311.3	311.3
1979	315.0	316.6	319.3	322.5	325.1	327.8	352.4	362.0	364.2	366.8	369.0	371.7

Table 6.2 Davies Belfield & Everest Building Cost Indices 1971 - 1979 (Base 1970 = 100)

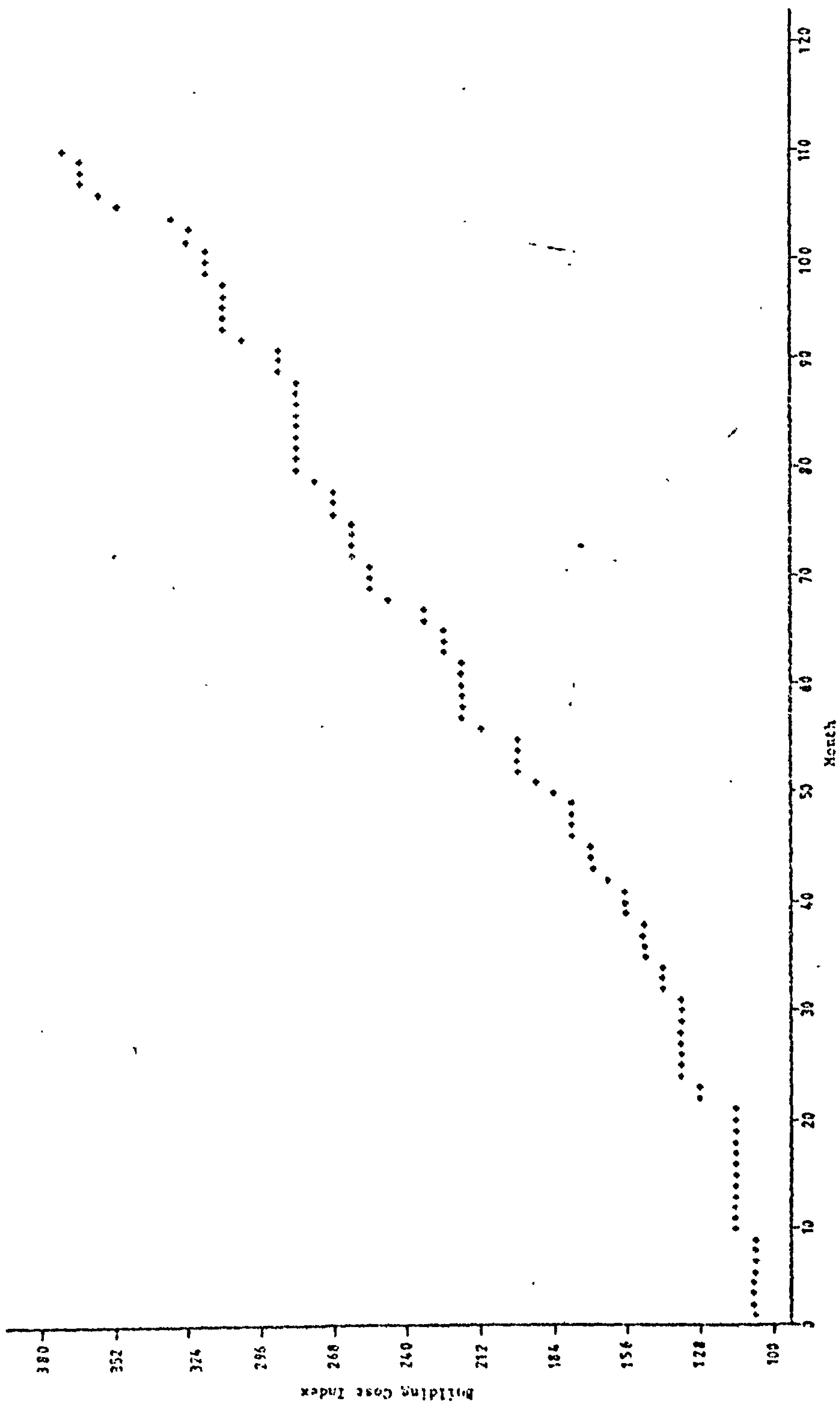


Fig 6.2 Building Cost Indices 1971 - 1979 (Base 1970 = 100)

Range-Mean Plot

The time series is grouped into a sample of 10 or according to seasonality. The difference between minimum and maximum is the range for that group, and the mean is the average of the values taken, e.g.

	GROUP			
Data Points	Maximum	Minimum	Range	Mean
1-10	110.8	104.3	6.5	108.1
11-20	114	110.8	3.2	112.1
21-30	137.3	124.6	7.7	133.6
31-40	158.8	141.9	16.9	148.9
51.50	219.6	195	24.6	209.0
61-70	255	222.1	32.9	237.6
71-80	280.7	258	22.7	268.0
81-90	289.8	280.7	9.1	289.6
91-100	322.5	304.8	17.7	312.6

Then the maximum range is divided by 31 and scales are marked and printed after every four values.

For graph (b), the logarithm of the series is taken and the range-mean calculated and plotted in the same manner.


BUILDING COST INDICES 1971-79
BASE SERIES WITHOUT DIFFERENCING
GRAPH OF RANGE AGAINST MEAN
SAMPLE SIZE 10
Range
32·90
28·94
24·98
21·02
17·06
13·10
9·14
5·18
100
210
320
Mean Index Value
(a)
BUILDING COST INDICES 1971 - 79
LOGARITHMIC TRANSFORMED SERIES WITHOUT DIFFERENCING
GRAPH RANGE AGAINST MEAN
Range
0·17920143
0·13900683
0·11890953
0·09881223
0·07871493
0·05861763
4·90
5·20
5·80
Mean Index Value
(b)

Fig. 6.3

BUILDING COST INDICES 1971 TO 1979 (BASE 1970)

TRANSFORMED SERIES WITHOUT DIFFERENCE

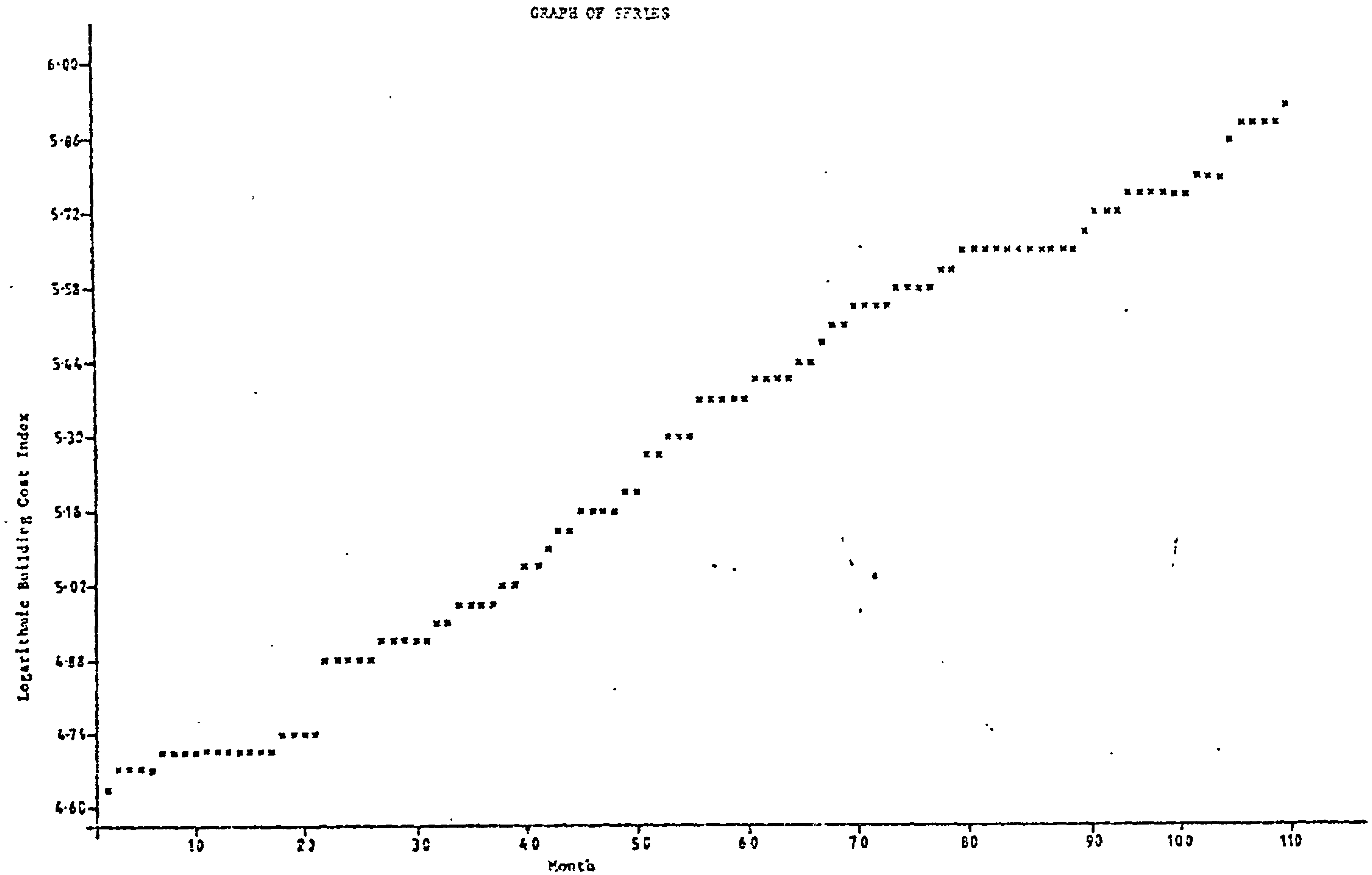


Fig 6.4

lag	Autocorrelation	Partial Autocorrelation
0	1.0	
1	0.975	0.975
2	0.949	-0.022
3	0.923	-0.023
4	0.896	-0.013
5	0.87	-0.016
6	0.845	0.003
7	0.821	0.027
8	0.797	-0.019
9	0.773	-0.023
10	0.749	-0.019
11	0.724	-0.025
12	0.698	-0.025

Approximate standard error 1/sqrt(n) = 0.096

Chi-squared statistic = 913.24

for 12 degrees of freedom

Building Cost Indices Series 1971-79

Autocorrelations and partial autocorrelations of the transformed series without differencing

Table 6.3

BUILDING COST INDICES 1971 - 79

TRANSFORMED SERIES WITHOUT DIFFERENCING

Fig. 6.5

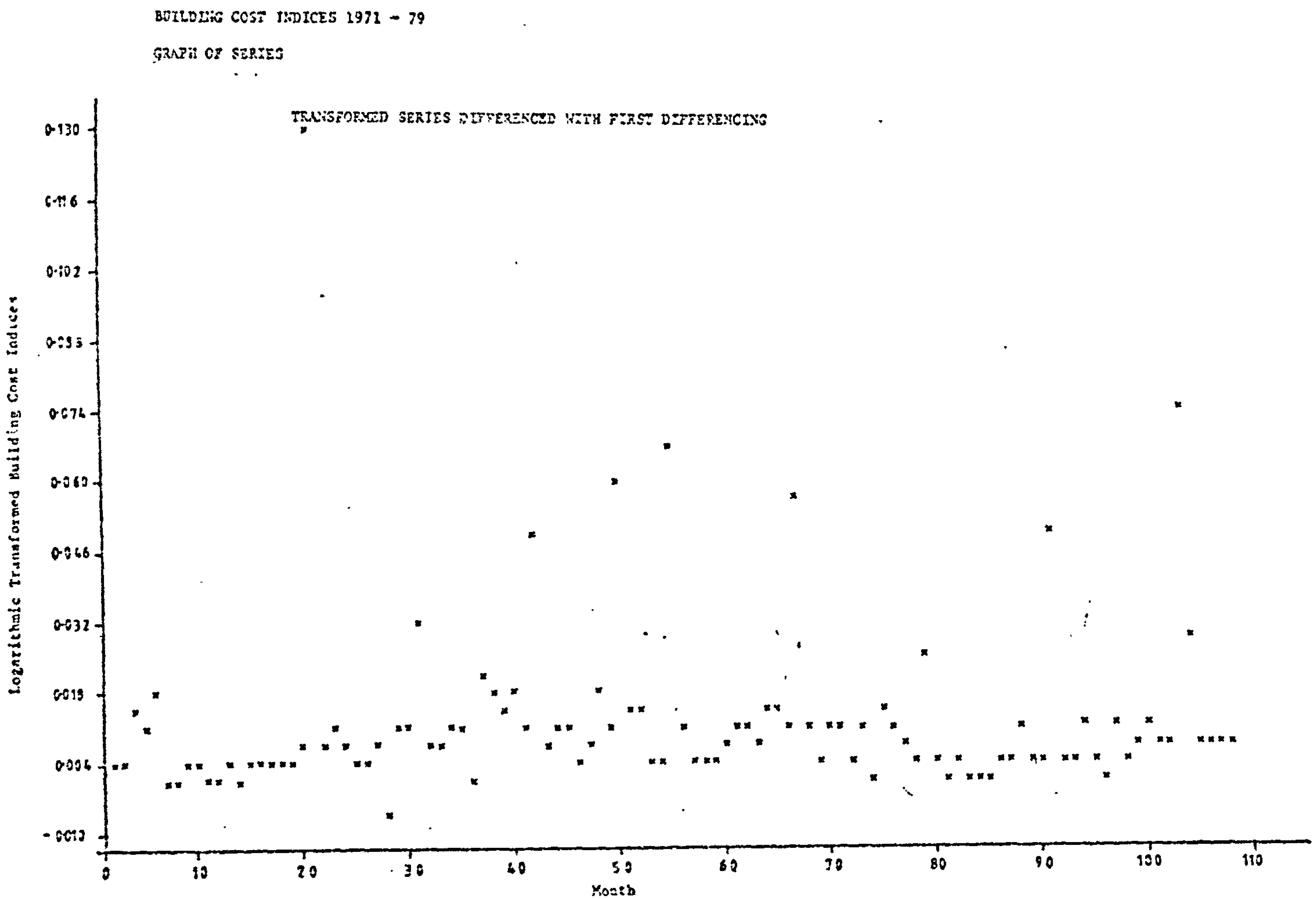

BUILDING COST INDICES 1971 - 79
GRAPH OF SERIES
TRANSFORMED SERIES DIFFERENCED WITH FIRST DIFFERENCING
0·130
0·116
0·102
0·074
0·060
0·046
0·032
0·019
0·004
-0·010
Logarithmic Transformed Building Cost Indices
0
10
20
30
40
50
60
70
80
90
100
110
Month

Fig 6.6

lag	Autocorrelation	Partial Autocorrelation
0	1.0	
1	0.024	0.024
2	-0.026	-0.027
3	-0.025	-0.024
4	-0.072	-0.072
5	0.004	0.006
6	-0.022	-0.027
7	-0.131	-0.134
8	0.024	0.024
9	-0.038	-0.048
10	0.032	0.025
11	-0.026	-0.049
12	0.167	0.178

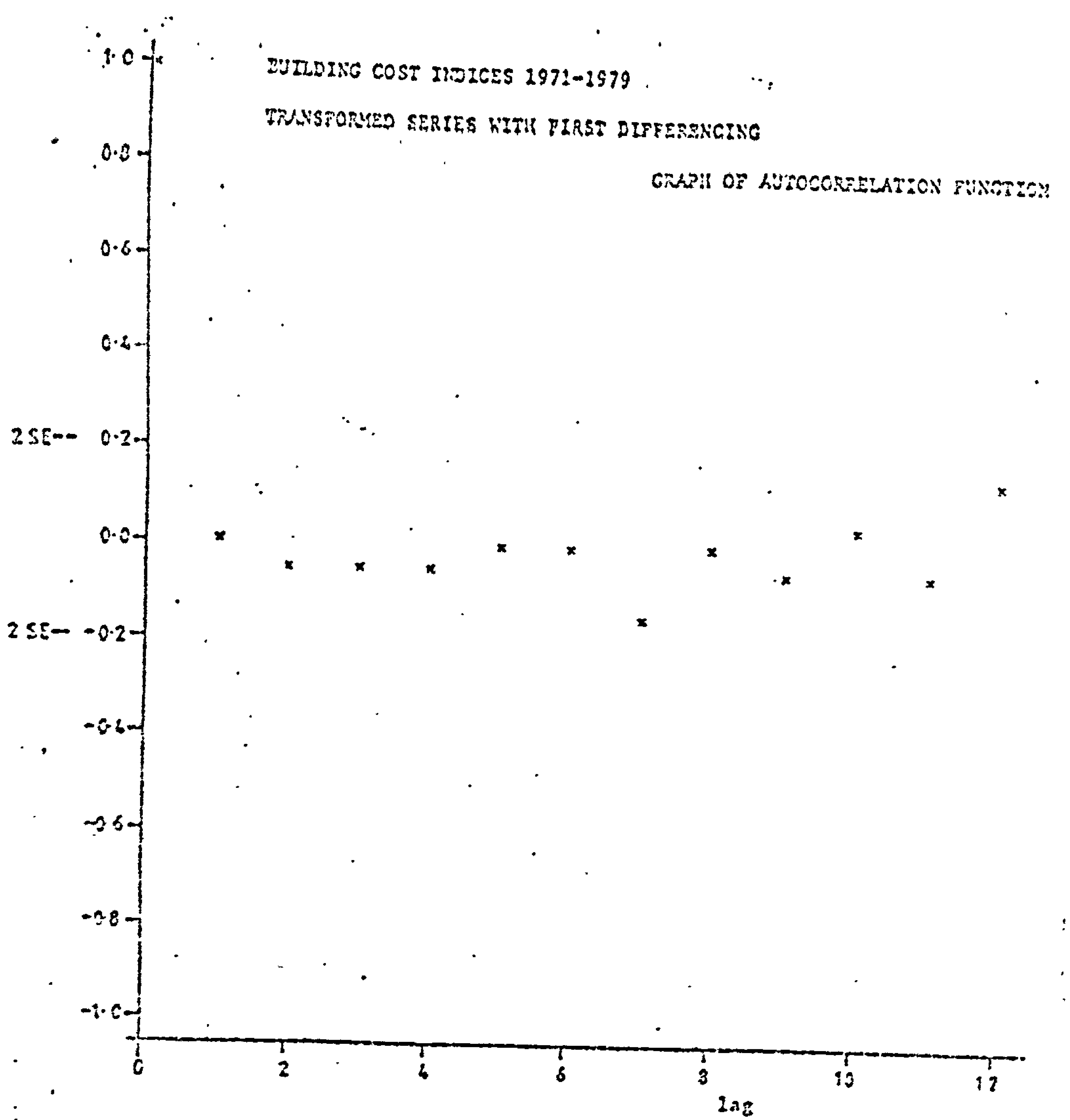
Approximate standard error 1/sqrt(n) = 0.097

χ^2-statistic = 6.04 for 12 degrees of freedom.

Building Cost Indices Series 1971-79

Auto and Partial autocorrelations of the transformed series with differencing.

Table 6.4


BUILDING COST INDICES 1971-1979
TRANSFORMED SERIES WITH FIRST DIFFERENCING
GRAPH OF AUTOCORRELATION FUNCTION
1·0
0·8
0·6
0·4
2 SE-- 0·2
0·0
2 SE-- -0·2
-0·4
-0·6
-0·8
-1·0
0
2
4
6
8
10
12
lag

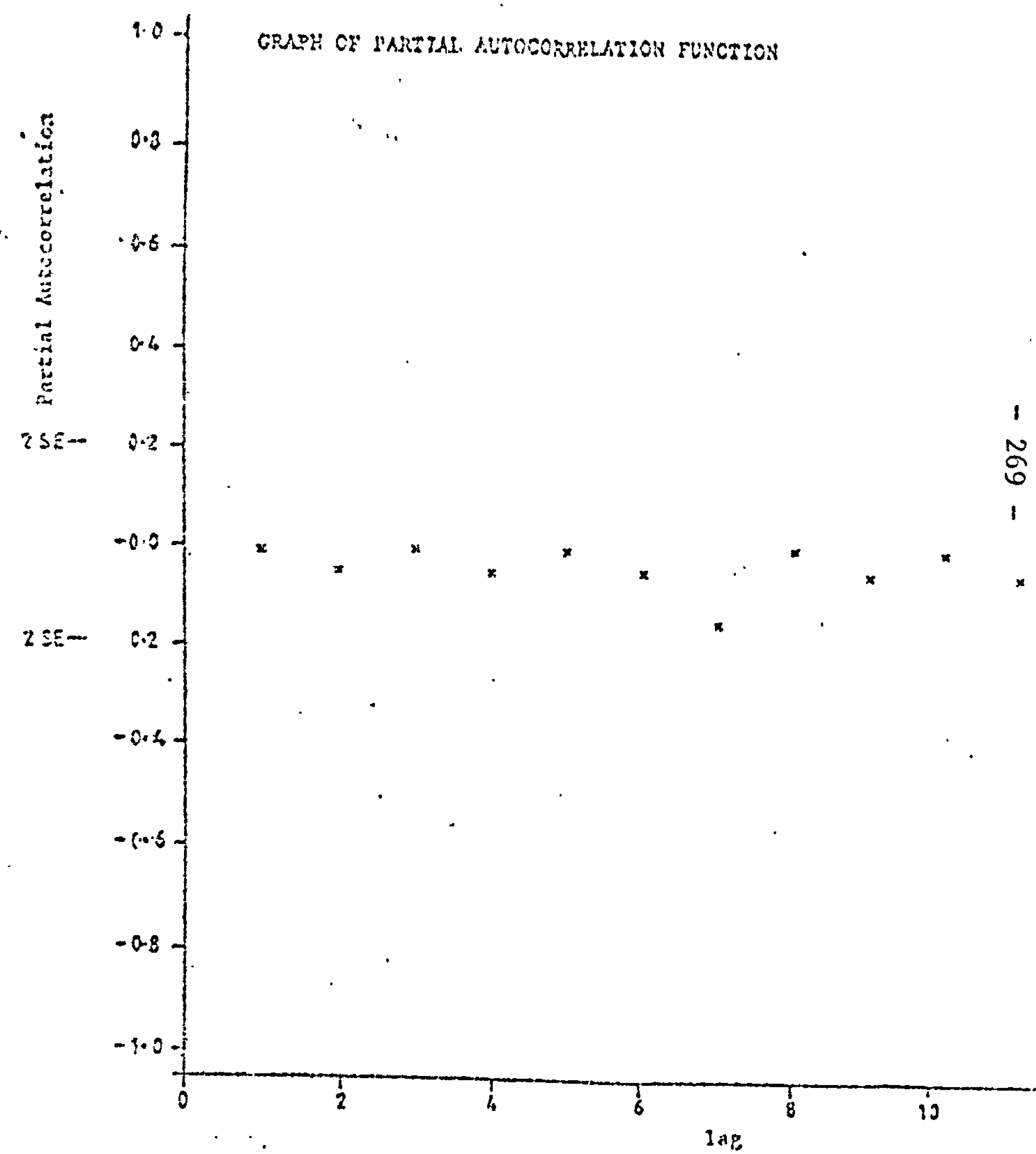

GRAPH OF PARTIAL AUTOCORRELATION FUNCTION
Partial Autocorrelation
1·0
0·8
0·6
0·4
2 SE-- 0·2
-0·0
2 SE-- 0·2
-0·4
-0·6
-0·8
-1·0
0
2
4
6
8
10
lag

Fig. 6.7

1979	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
L	312	315	316.6	319.3	322.5	325.1	327.8	352.4	362.0	364.2	366.8	369.0
F	315.7	318.8	320.4	323.1	326.4	329.0	331.7	356.6	366.3	368.6	371.2	373.4
Actual	315.0	316.6	319.3	322.5	325.0	327.8	352.4	362.0	364.0	366.8	369.0	371.7
U	319.5	322.6	324.2	327.0	330.2	332.9	335.7	360.9	370.7	372.9	375.6	377.9

1980

L	371.7	374.3	377.4	380.7	384.1	387.7	391.5	395.3	399.2	403.2	407.3	411.4
DBE F	373.8	375.9	378.6	380.7	382.9	385.6	415.0	417.1	419.8	421.9	424.1	426.7
F	376.1	380.6	385.2	389.8	394.4	399.2	403.9	408.8	413.6	418.6	423.6	428.6
U	380.6	387.1	393.2	399.1	405.0	410.9	416.8	422.7	428.6	434.6	440.6	446.6

1981

L	415.6	419.9	424.3	428.7	433.2	437.7	442.4	447.0	451.8	456.6	461.5	466.4
F	433.8	438.9	444.2	449.5	454.9	460.3	465.8	471.4	477.0	482.7	488.5	494.3
U	452.7	458.8	465.1	471.3	477.6	484.0	490.5	497.0	503.6	510.3	517.0	523.8

(Base 1970 = 100)

Key L : Lower (50% Probability) limit
U : Upper (50% Probability) limit
F : Forecasts from the identified Box-Jenkins model
DB&E F : Davies Belfield & Everest forecasts

Table 6.5 Forecasts of DBE Building Cost Indices for 1980 and 1981 Using Box-Jenkins (0,1,0) ARIMA model

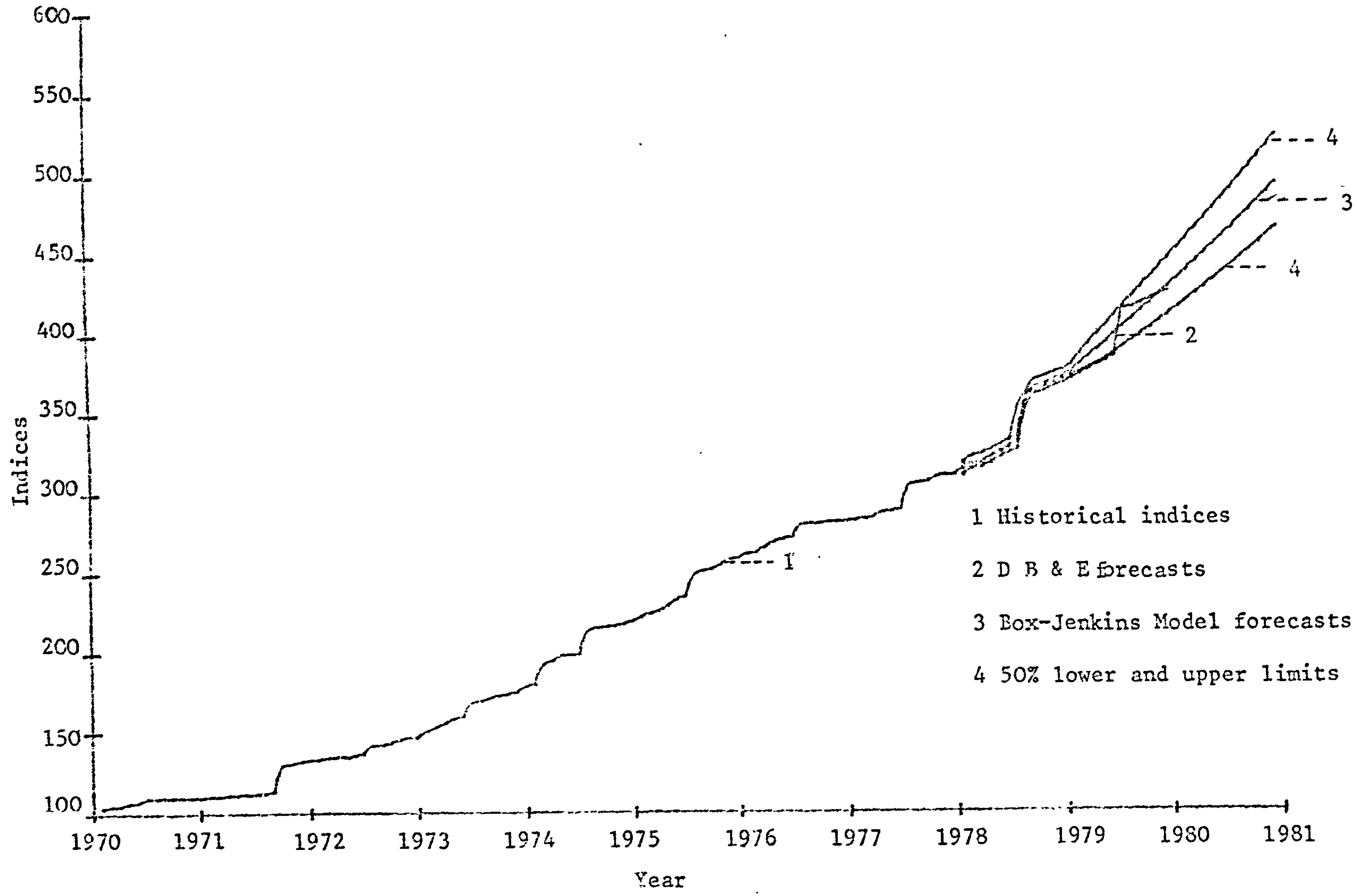


Fig 6.8 Forecasts of D B & E Building Cost Indices for 1979-81 (Base 1970 = 100) using Box-Jenkins (0, 1, 0) ARIMA model

Year \ Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1971	104.4	104.5	104.5	106.1	106.1	108.5	108.9	108.9	108.9	109.4	109.4	109.4
1972	110.0	110.0	110.0	110.0	110.0	110.0	110.0	110.0	138.8	139.5	140.2	141.9
1973	141.9	141.9	141.9	138.8	138.8	138.8	143.5	144.1	144.1	144.1	144.1	144.1
1974	144.1	144.4	144.4	145.0	145.0	158.2	160.7	162.7	165.2	165.2	166.8	170.3
1975	170.3	189.1	189.1	192.8	192.8	192.8	217.0	218.3	218.3	218.3	218.3	219.5
1976	219.5	219.5	219.5	221.3	221.3	221.3	241.4	241.4	241.4	243.2	243.2	243.2
1977	243.8	243.8	243.8	247.7	247.7	247.7	258.7	259.2	259.2	259.2	259.2	259.2
1978	259.2	259.2	259.2	261.7	262.0	262.0	289.0	290.7	290.7	294.1	294.1	294.1
1979	294.2	294.2	294.2	294.2	294.2	335.3	344.5	344.5	344.5	344.5	344.5	344.5

Table 6.6 Davies Belfield & Everest Labour Indices 1971 - 1979 (Base 1970 = 100)

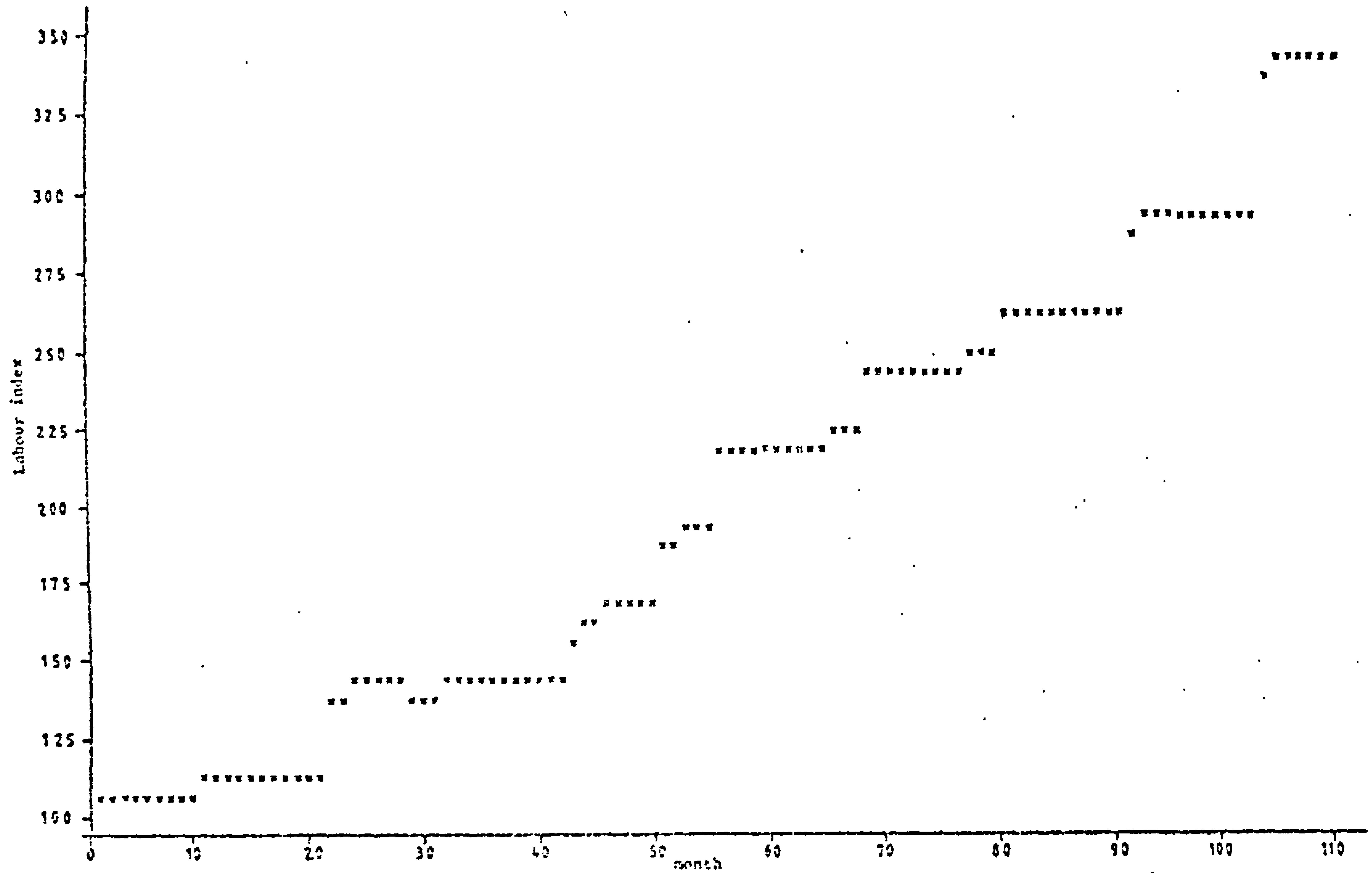
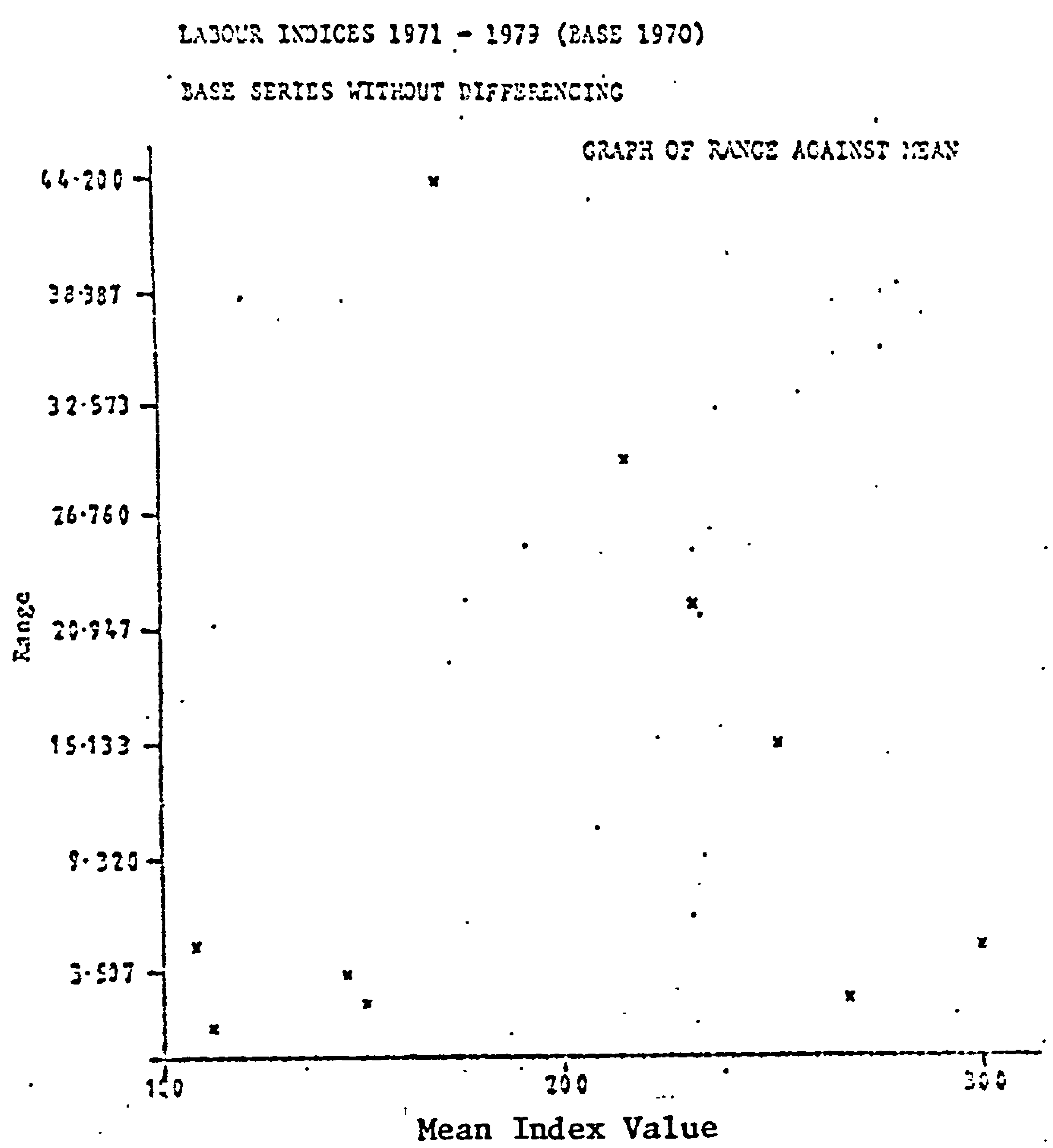
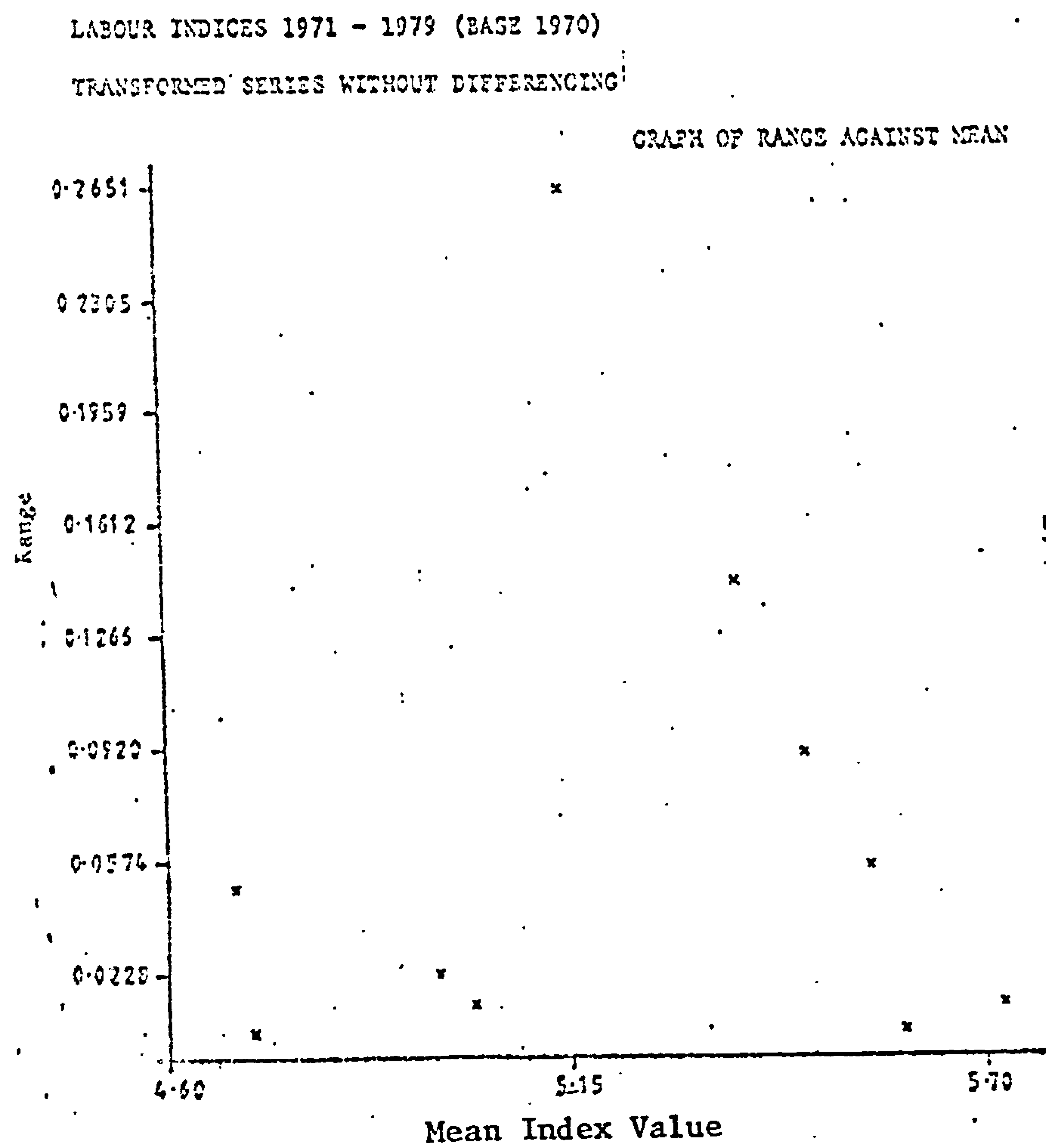


Fig 6.9 Davies Belfield & Everest Labour Indices 1971 - 1979 (Base 1970 = 100)


LABOUR INDICES 1971 - 1979 (BASE 1970)
BASE SERIES WITHOUT DIFFERENCING
GRAPH OF RANGE AGAINST MEAN
44·200
38·387
32·573
26·760
20·947
15·133
9·320
3·507
Range
100
200
300
Mean Index Value

(a)


LABOUR INDICES 1971 - 1979 (BASE 1970)
TRANSFORMED SERIES WITHOUT DIFFERENCING
GRAPH OF RANGE AGAINST MEAN
0·2651
0·2305
0·1959
0·1612
0·1265
0·0920
0·0574
0·0228
Range
4·60
5·15
5·70
Mean Index Value

(b)

Fig. 6.10

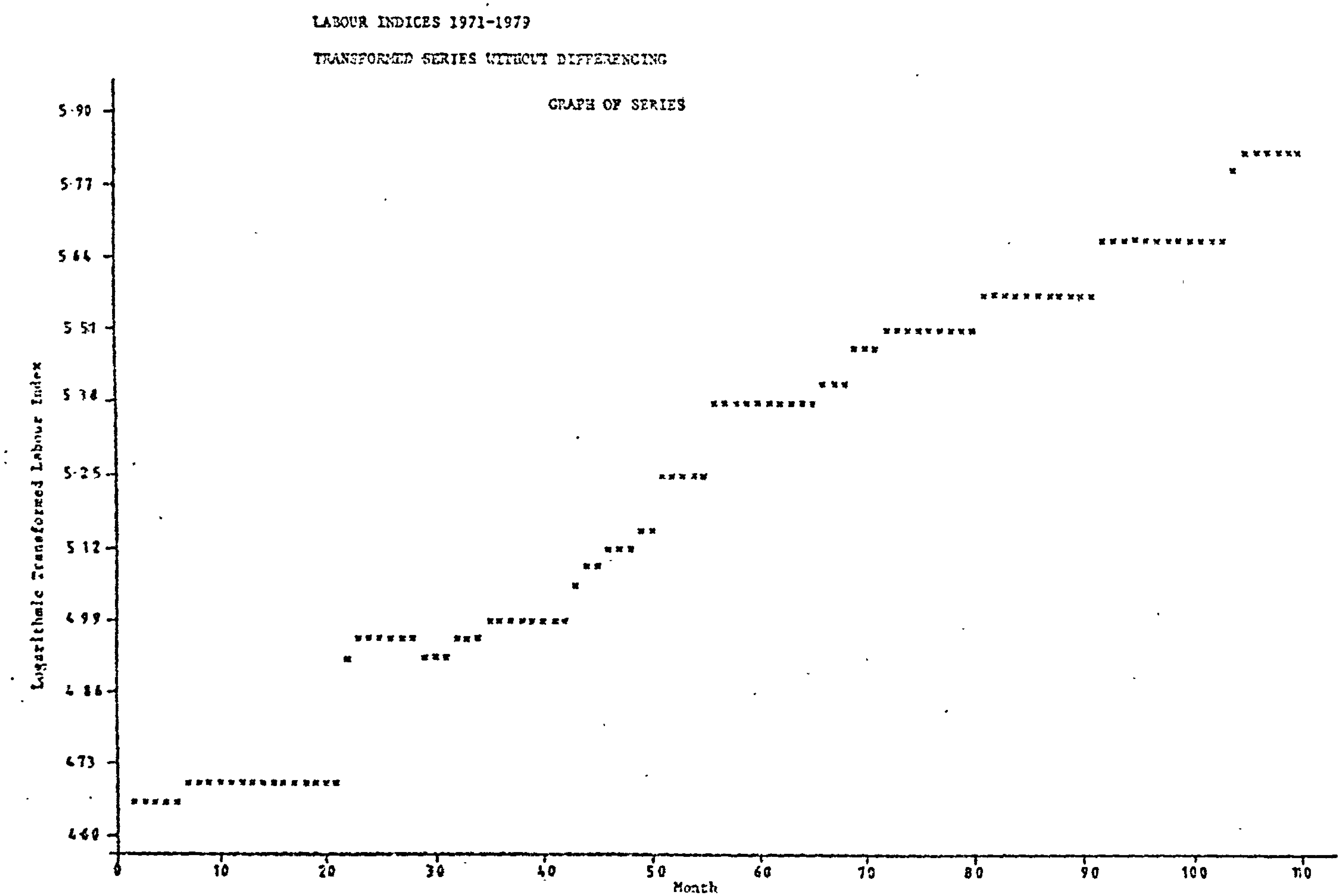

LABOUR INDICES 1971-1979
TRANSFORMED SERIES WITHOUT DIFFERENCING
GRAPH OF SERIES
Logarithmic Transformed Labour Index
5·90
5·77
5·64
5·51
5·38
5·25
5·12
4·99
4·86
4·73
4·60
0
10
20
30
40
50
60
70
80
90
100
110
Month

Fig. 6.11

lag	Autocorrelation	Partial Autocorrelations
0	1.0	
1	0.972	0.972
2	0.943	-0.025
3	0.913	-0.024
4	0.884	-0.017
5	0.854	-0.017
6	0.824	-0.019
7	0.795	0.003
8	0.772	0.076
9	0.747	-0.032
10	0.723	-0.017
11	0.697	-0.031
12	0.670	-0.043

Approximate standard error $1/\sqrt{n} = 0.096$

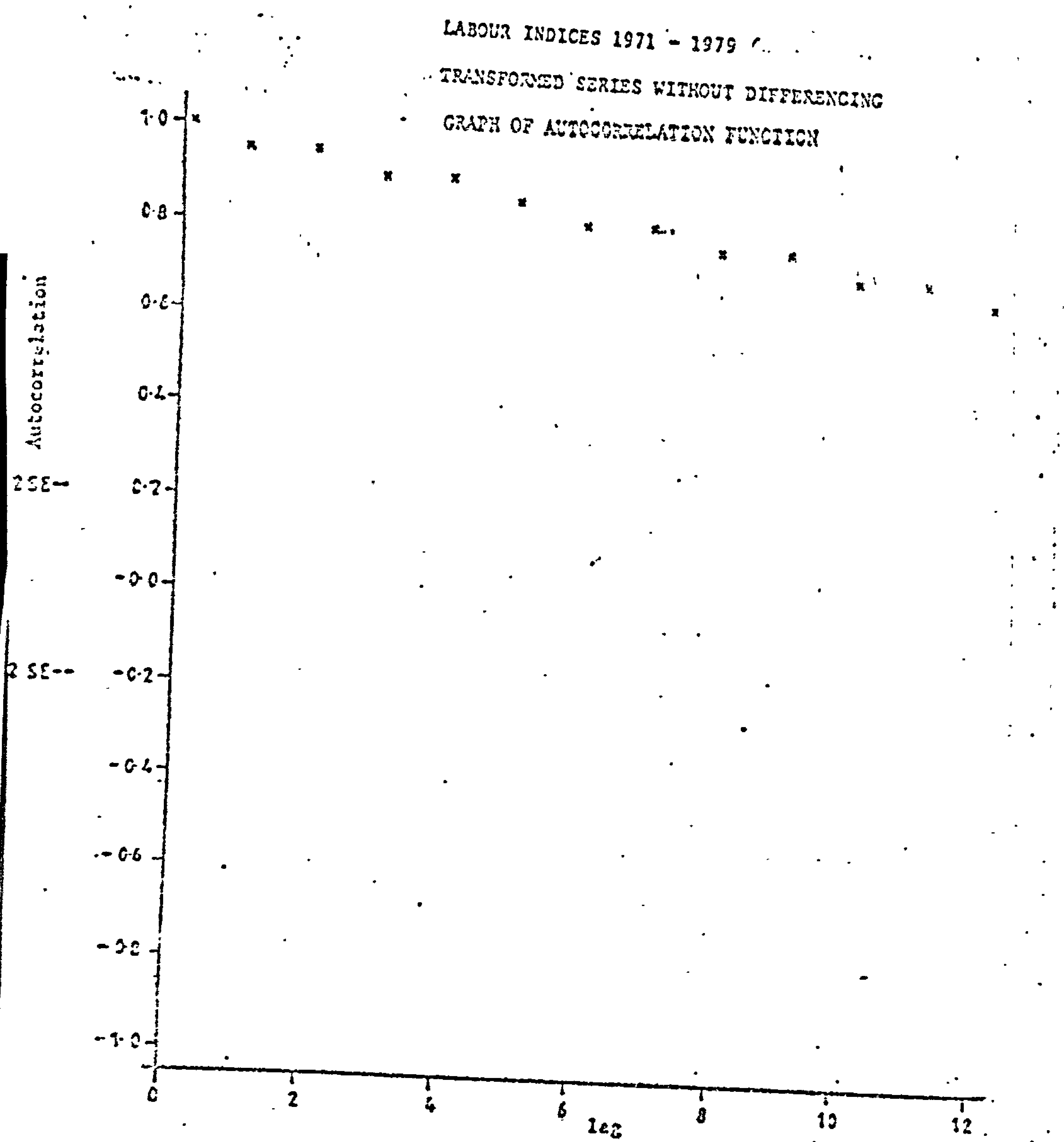
Chi-squared statistic = 874.71

for 12 degrees of freedom

Labour Indices Series 1971-79

Autocorrelations and Partial autocorrelations of the transformed series without differencing

Table 6.7


LABOUR INDICES 1971 - 1979
TRANSFORMED SERIES WITHOUT DIFFERENCING
GRAPH OF AUTOCORRELATION FUNCTION
Autocorrelation
2SE
2 SE
1·0
0·8
0·6
0·4
0·2
-0·0
-0·2
-0·4
-0·6
-0·8
-1·0
0
2
4
6
8
10
12
lag

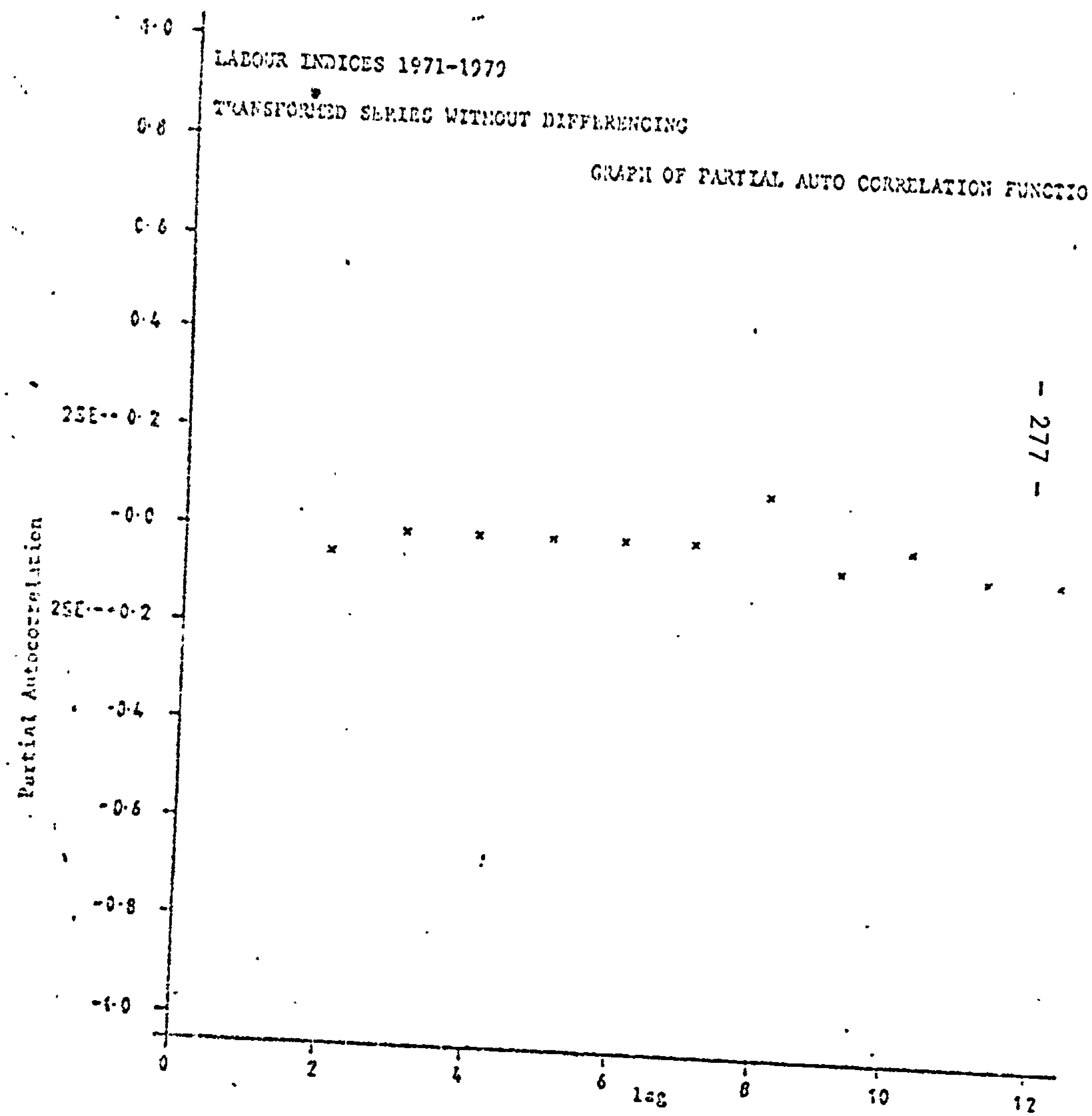

LABOUR INDICES 1971-1979
TRANSFORMED SERIES WITHOUT DIFFERENCING
GRAPH OF PARTIAL AUTO CORRELATION FUNCTIO
Partial Autocorrelation
1·0
0·8
0·6
0·4
2SE 0·2
-0·0
2SE -0·2
-0·4
-0·6
-0·8
-1·0
0
2
4
6
8
10
12
lag

Fig 6.12

LABOUR INDICES 1971-79

GRAPH OF SERIES
CORRESPONDING TO TRANSFORMED SERIES WITH FIRST DIFFERENCING

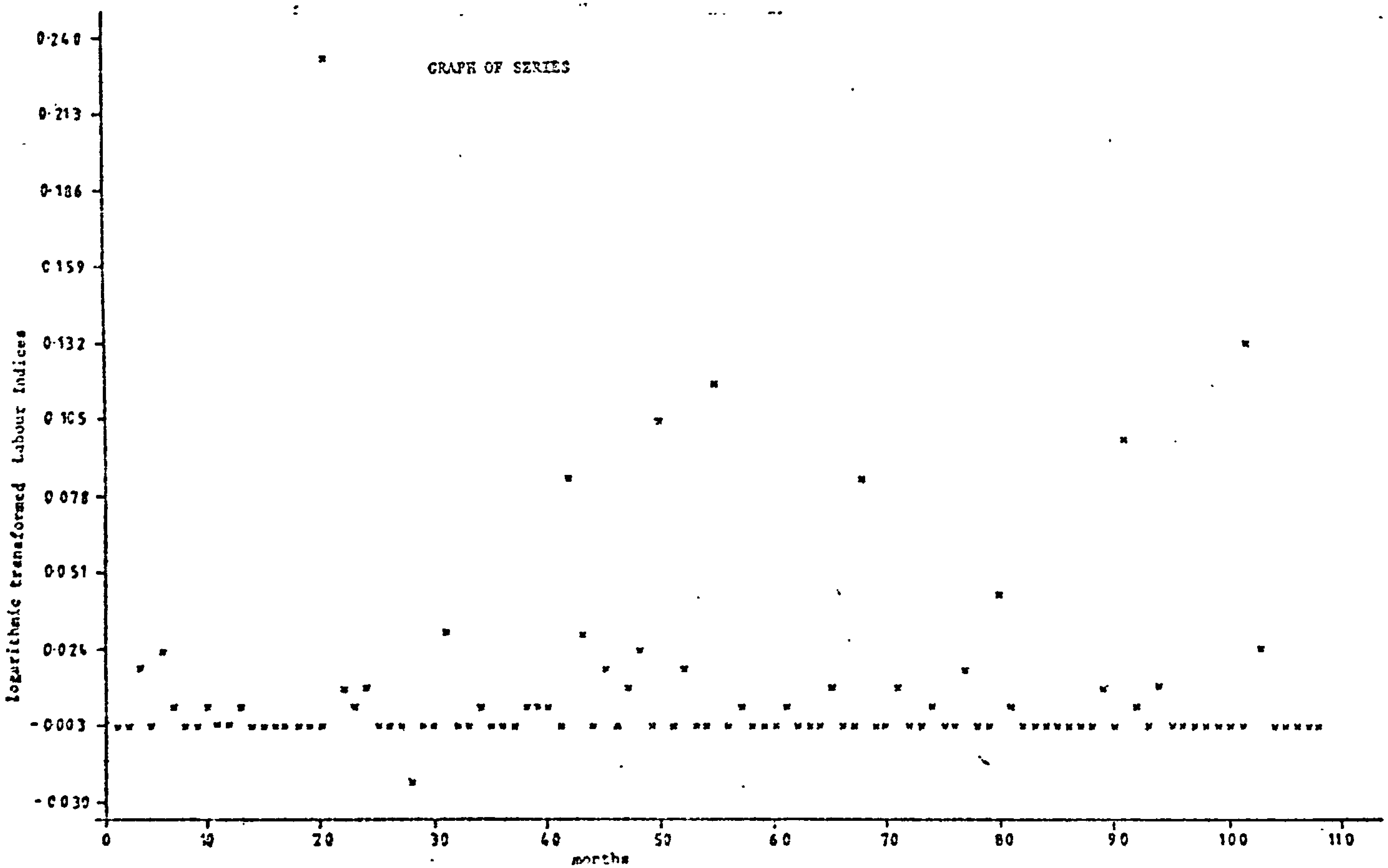


Fig 6.13

lag	Autocorrelation	Partial Autocorrelation
0	1.0	
1	-0.039	-0.039
2	-0.05	-0.052
3	-0.025	-0.029
4	-0.11	-0.116
5	0.022	0.009
6	-0.09	-0.104
7	-0.081	-0.097
8	0.012	-0.022
9	-0.071	-0.09
10	0.013	-0.028
11	0.087	0.058
12	0.004	-0.014

Approximate standard error $1/\sqrt{n} = 0.097$

Chi-squared statistic = 4.81

for 12 degrees of freedom

Labour Indices Series 1971-79

Autocorrelation and Partial Autocorrelations of the transformed series with first differencing

Table 6.8


GRAPH OF AUTOCORRELATION FUNCTION
Autocorrelation
1·0
0·8
0·6
0·4
2SE
0·2
0·0
-0·2
-0·4
-0·6
-0·8
-1·0
0
2
4
6
8
10
12
lag
LABOUR INDICES 1971-1979
TRANSFORMED SERIES WITH FIRST DIFFERENCING
GRAPH OF PARTIAL AUTOCORRELATION FUNCTION
Partial autocorrelation

Fig 6.14

1979	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
L	290.8	290.9	290.9	290.9	290.9	290.9	331.5	340.7	340.7	340.7	340.7	340.7
F	297.4	297.5	297.5	297.5	297.5	297.5	339.1	348.4	348.4	348.4	348.4	348.4
Actual	294.2	294.2	294.2	294.2	294.2	335.3	344.5	344.5	344.5	344.5	344.5	344.5
U	304.1	304.2	304.2	304.2	304.2	304.2	346.7	356.2	356.2	356.2	356.2	356.2

1980

L	340.7	341.3	342.7	344.4	346.5	348.7	351.0	353.5	356.1	358.8	361.5	364.4
F	348.4	352.3	356.2	360.2	364.2	368.3	372.4	376.6	380.8	385.0	389.3	393.7
DBE F	344.5	344.5	344.5	344.5	344.5	344.5	396.2	396.2	396.2	396.2	396.2	396.2
U	356.2	363.6	370.2	376.6	382.9	389.0	395.1	401.1	407.2	413.2	419.3	425.4

1981

L	367.3	370.3	373.3	376.4	379.6	382.8	386.1	389.4	392.8	396.2	399.7	403.3
F	398.1	402.5	407.0	411.6	416.2	420.9	425.6	430	435.1	440.0	444.9	449.9
DBE F	396.2	396.2	396.2	396.2	396.2	396.2						
U	431.5	437.6	443.8	450.1	456.3	462.7	469.1	475.5	482.0	488.6	495	501.9

Key : L : Lower (50% Probability) limit
U : Upper (50% Probability) limit
F : forecasts from the identified Box-Jenkins model
DB & E F : Davies Belfield & Everest forecasts

(Base 1970 = 100)

Table 6.9 Forecasts of DB & E Labour Indices for 1980 and 1981 using Box-Jenkins (0,1,0) ARIMA model

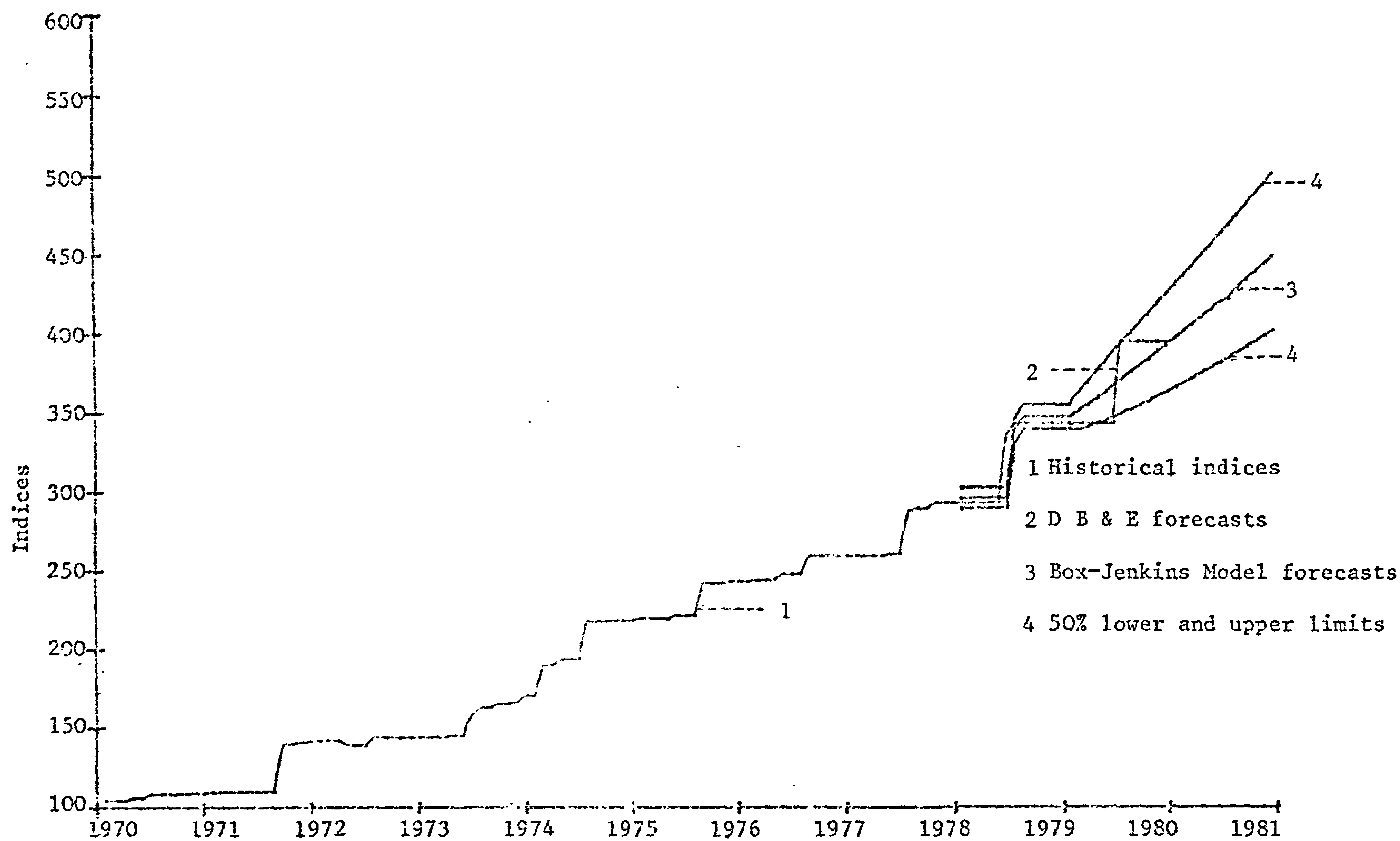


Fig 6.15 Forecasts of D B & E Labour Indices 1979-81 (Base 1970 = 100) using Box-Jenkins (0,1,0) ARIMA model

Year \ Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1971	104.5	105.3	106.1	107.6	109.9	110.7	111.5	111.5	112.3	112.3	112.3	112.3
1972	113.1	113.1	113.8	114.6	115.3	116.1	116.9	118.5	119.2	120.8	123.1	123.1
1973	124.3	125.2	127.5	129.2	132.4	135.2	140.3	142.8	145.3	149.9	149.9	151.9
1974	158.3	164.1	169.0	174.4	178.8	179.7	180.1	181.2	183.0	183.9	185.2	187.6
1975	192.6	195.4	201.5	203.7	205.5	206.8	208.6	212.2	213.6	215.1	217.4	219.6
1976	225.0	229.9	233.1	237.9	245.7	250.7	256.2	261.7	263.2	270.3	274.6	277.1
1977	282.1	287.4	290.4	293.0	297.0	300.0	303.1	304.8	304.8	307.2	308.5	308.8
1978	309.9	311.5	414.1	317.3	318.8	321.1	323.1	325.1	326.9	329.7	331.9	333.5
1979	338.2	342.4	348.2	354.1	360.6	366.1	372.6	381.9	386.6	392.5	397.5	402.4

Table 6.10 Department of Trade & Industry's Materials Indices 1971 - 1979 (Base 1970 = 100)

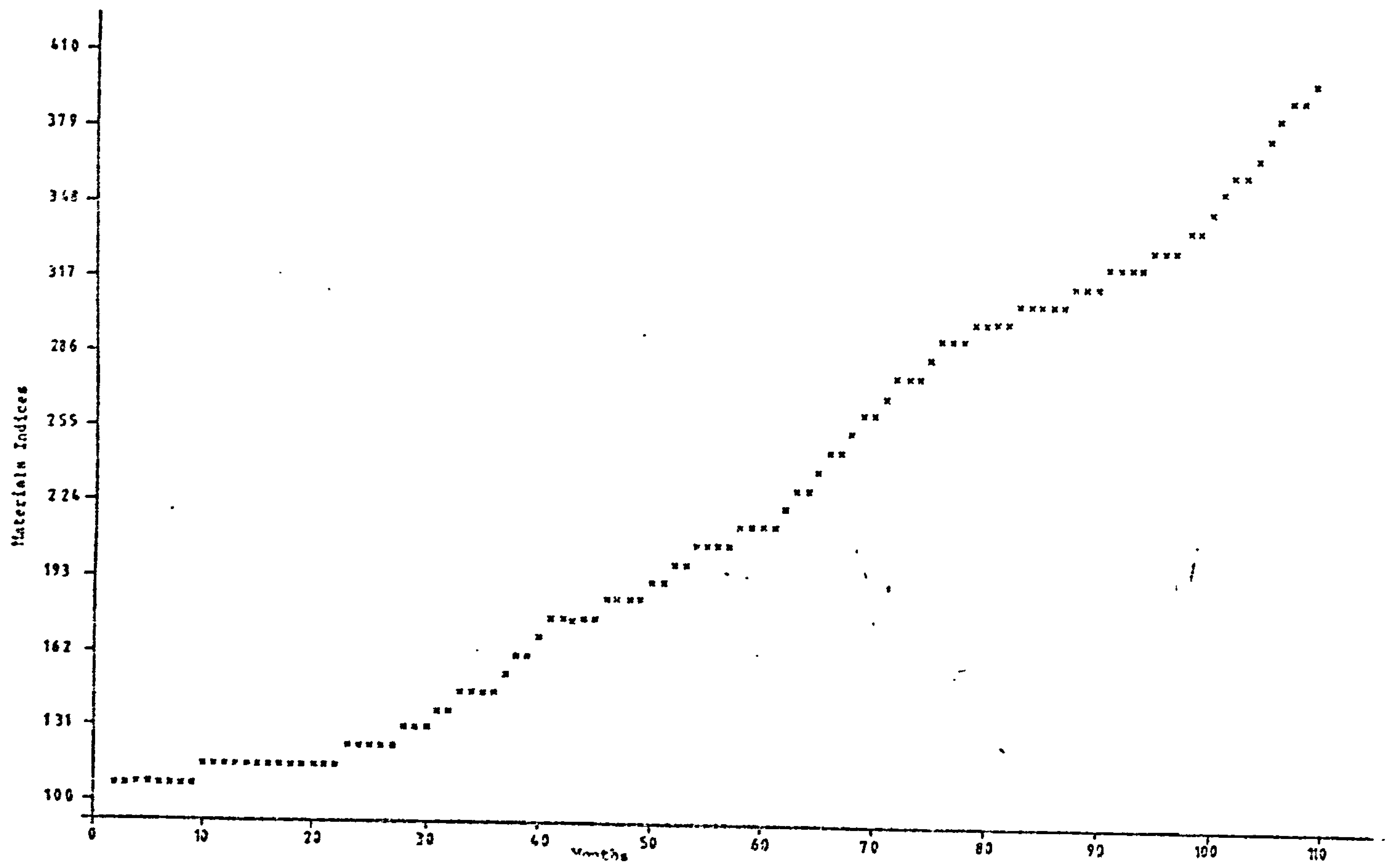


Fig 6.16 Department of Trade & Industry's Mateirals Indices 1971 - 1979 (Base 1970 = 100)

MATERIALS INDICES 1971-79

BASE SERIES WITHOUT DIFFERENCING

GRAPH OF RANGE AGAINST MEAN

MATERIALS INDICES 1971-79

TRANSFORMED SERIES WITHOUT DIFFERENCING

GRAPH OF RANGE AGAINST MEAN

Fig 6.17

MATERIALS INDICES 1971-79

TRANSFORMED SERIES WITHOUT DIFFERENCING

GRAPH OF SERIES

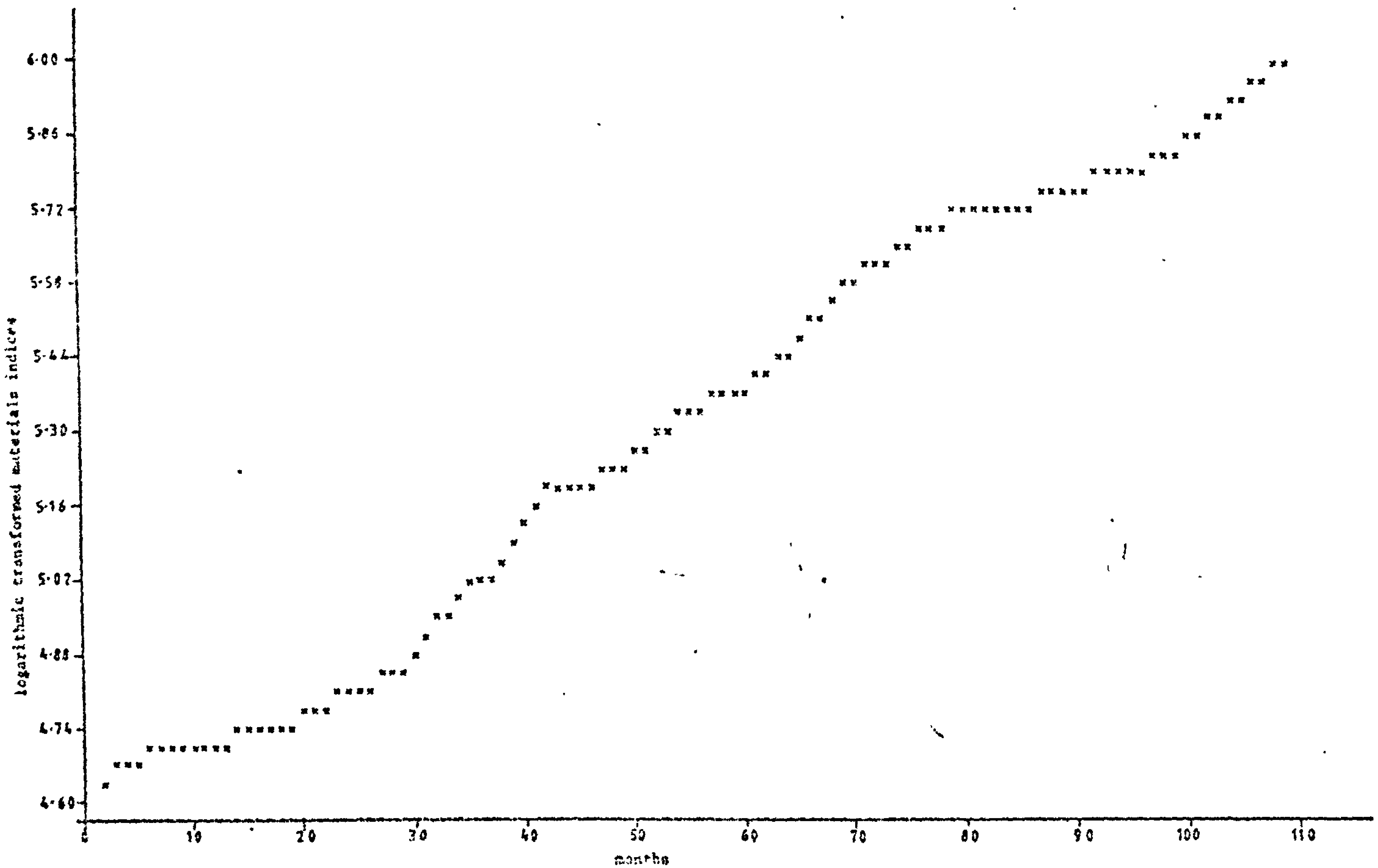
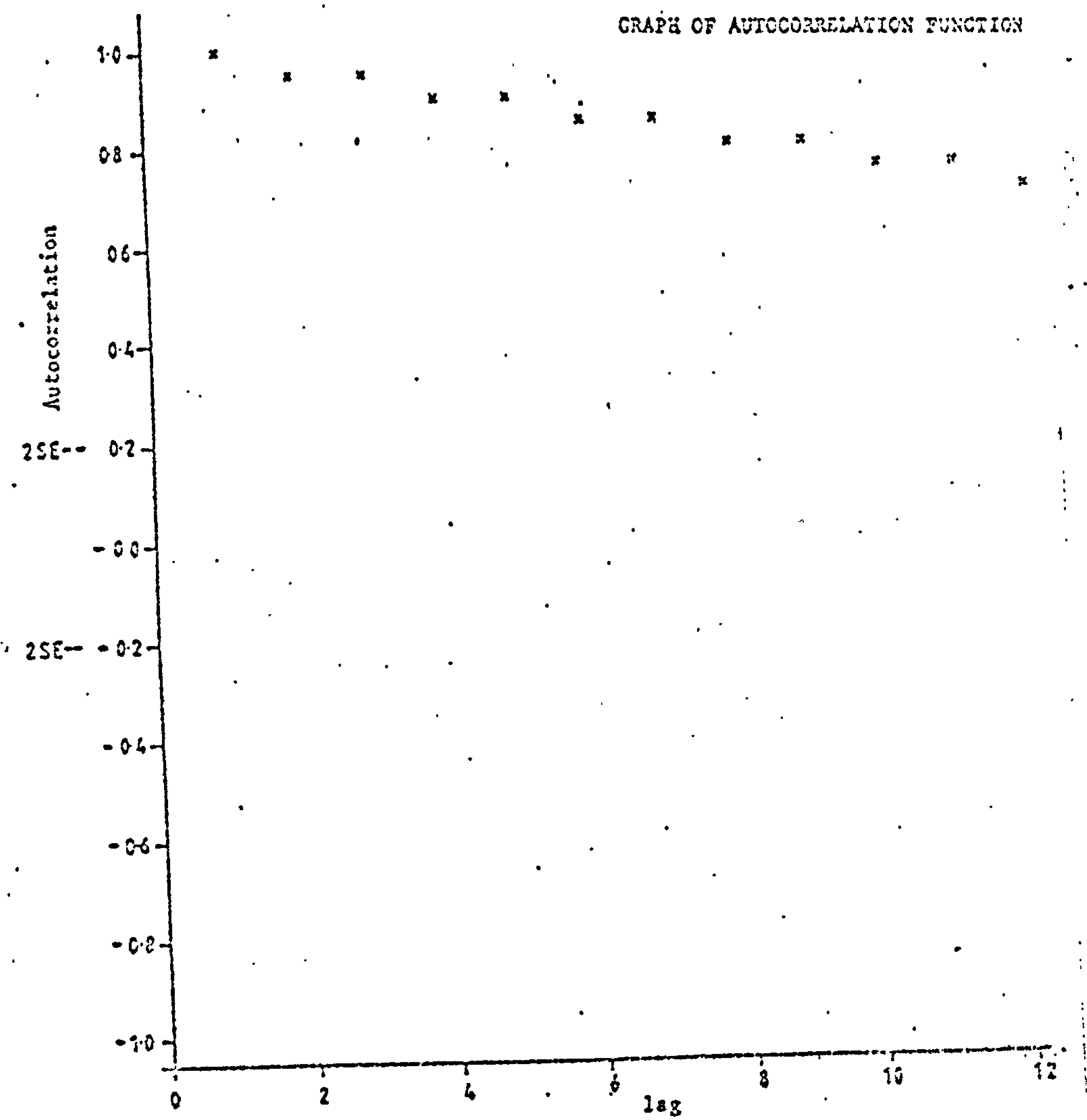


Fig 6.18

MATERIALS INDICES 1971-1979

TRANSFORMED SERIES WITHOUT DIFFERENCING



MATERIALS INDICES 1971-1979

TRANSFORMED SERIES WITHOUT DIFFERENCING

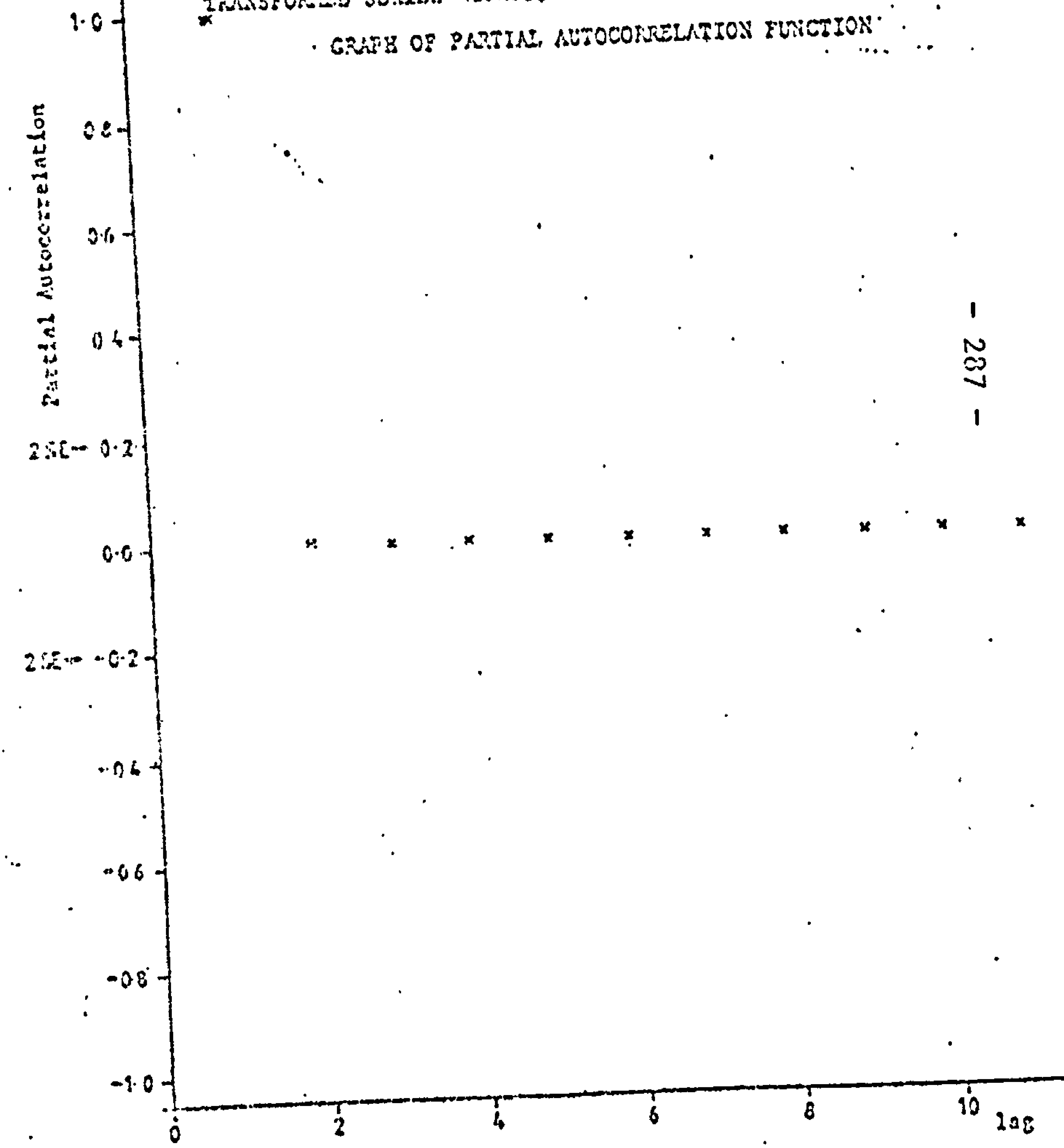


Fig 6.19

lag	autocorrelation	Partial autocorrelation
0	1	
1	0.976	0.976
2	0.952	-0.02
3	0.928	-0.019
4	0.903	-0.013
5	0.879	-0.008
6	0.855	-0.008
7	0.831	-0.013
8	0.806	-0.02
9	0.782	-0.013
10	0.757	-0.019
11	0.732	-0.019
12	0.707	-0.023

Approximate standard error $1/\sqrt{n} = 0.096$

Chi-squared statistic = 928.84

for 12 degrees of freedom

Materials Indices Series 1971-79

Autocorrelations and Partial autocorrelations of the transformed series without differencing.

Table 6.11

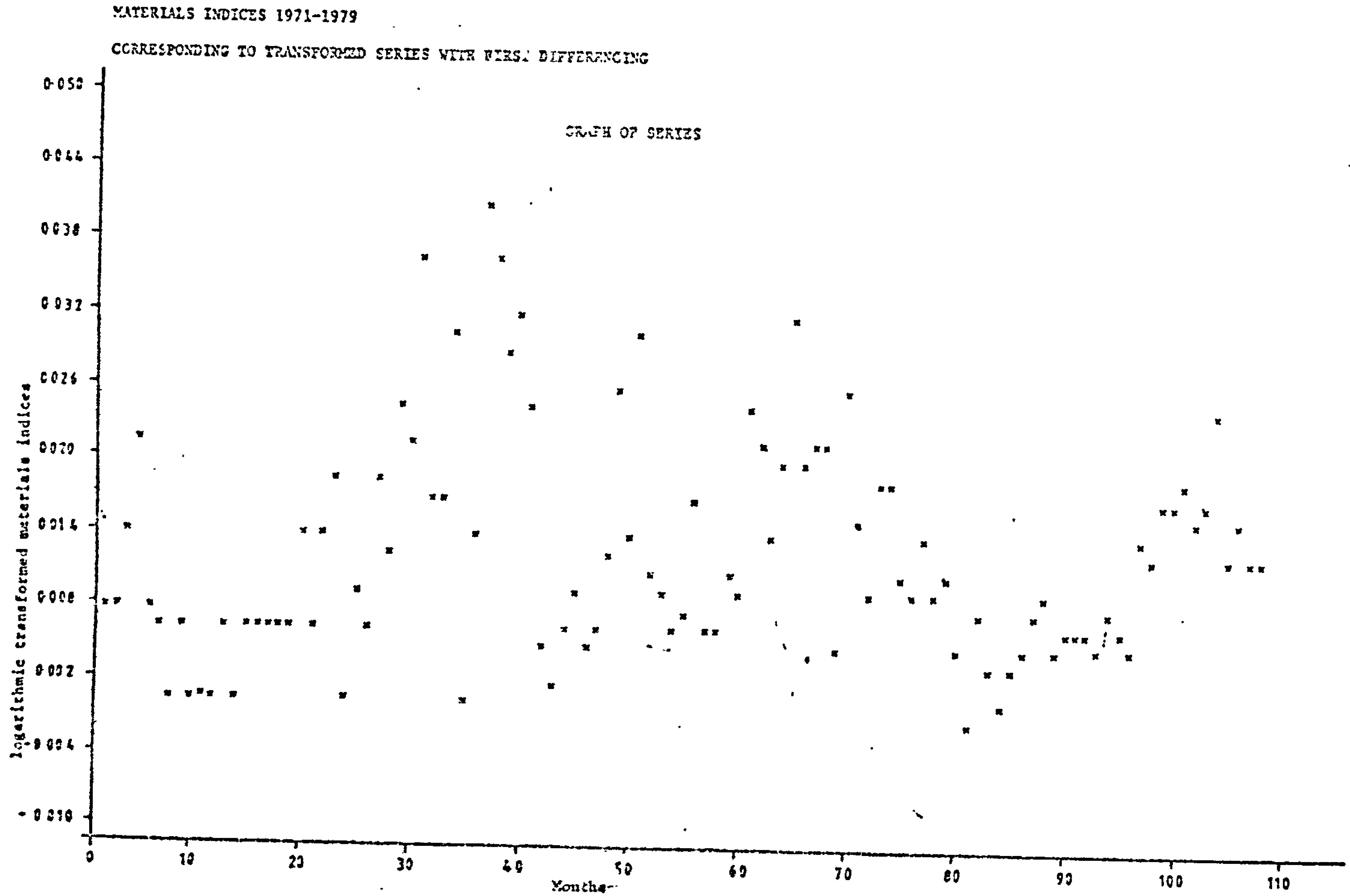

MATERIALS INDICES 1971-1979
CORRESPONDING TO TRANSFORMED SERIES WITH FIRST DIFFERENCING
GRAPH OF SERIES
logarithmic transformed materials indices
0·050
0·044
0·038
0·032
0·026
0·020
0·014
0·008
0·002
-0·004
-0·010
0
10
20
30
40
50
60
70
80
90
100
110
Months

Fig 6.20

lag	Autocorrelations	Partial Autocorrelations
0	1.0	
1	0.51	0.51
2	0.395	0.183
3	0.384	0.177
4	0.209	-0.103
5	0.107	-0.082
6	0.129	0.06
7	0.128	0.085
8	0.114	0.048
9	0.151	0.055
10	0.117	-0.036
11	0.135	0.05
12	0.045	-0.109

Approximate standard error $1/\sqrt{n} = 0.096$

Chi-squared statistic = 11.4

for 12 degrees of freedom

Materials Indices Series 1971-79

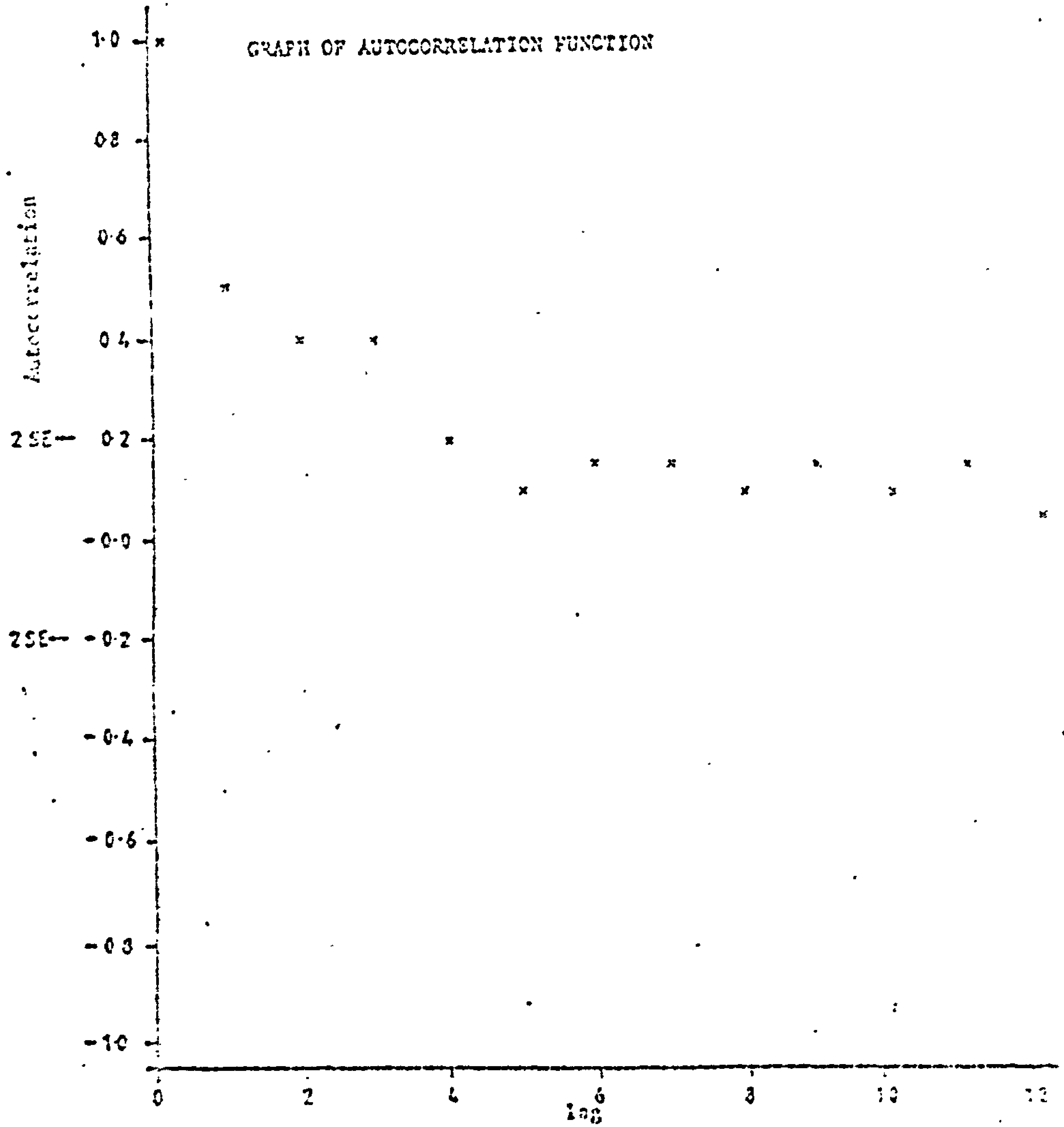
Autocorrelations and Partial autocorrelations of the transformed series with differencing.

Table 6.12

MATERIALS INDICES 1971 - 79

CORRESPONDING TO TRANSFORMED SERIES WITH FIRST DIFFERENCING

GRAPH OF AUTOCORRELATION FUNCTION



MATERIALS INDICES 1971 - 1979

CORRESPONDING TO TRANSFORMED SERIES WITH FIRST DIFFERENCING

GRAPH OF PARTIAL AUTOCORRELATION FUNCTION

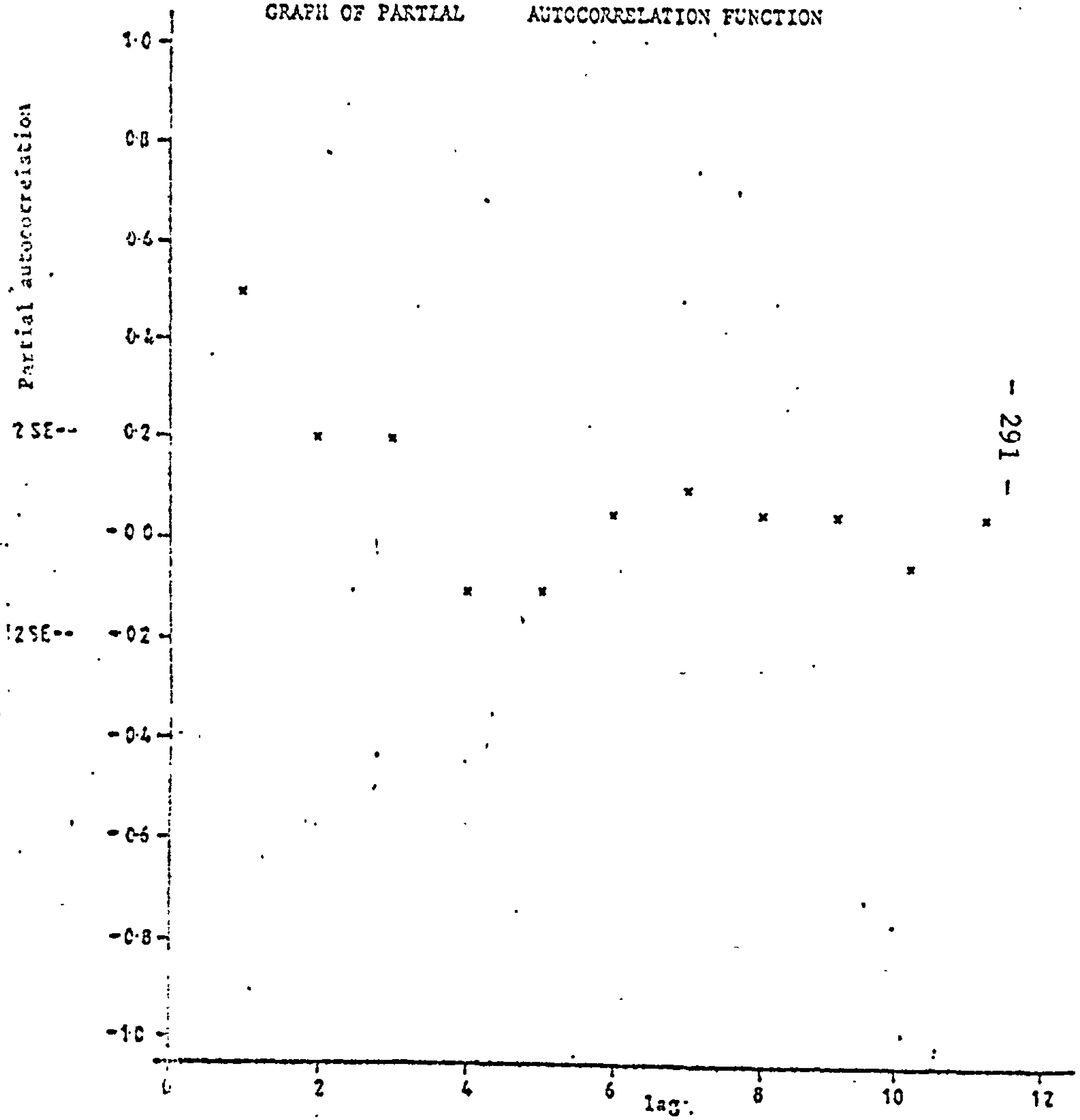


Fig 6.21

1979	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
L	334.6	340.9	344.9	351.5	357.5	364.3	369.3	376.3	387.1	389.4	395.9	400.5
F	336.4	342.7	346.7	353.4	359.4	366.2	371.2	378.3	389.1	391.4	398.0	402.5
Actual	338.2	342.4	348.2	354.1	360.6	366.1	372.6	381.9	386.6	392.5	397.5	402.4
U	338.1	344.5	348.5	355.2	361.2	368.1	373.2	380.3	391.2	393.5	400.1	404.6

1980

L	405.3	408.7	412.2	416.1	420.1	424.3	428.6	433.1	437.6	442.3	447.1	452.0
F	407.4	412.5	417.7	423.0	428.3	433.7	439.2	444.8	450.4	456.1	461.8	467.7
DBE F	407.3	412.1	417.0	422.0	426.9	431.8	436.6	441.6	446.5	451.4	456.4	461.1
U	409.6	416.4	423.3	430.0	436.7	443.4	450.1	456.8	463.5	470.2	477.0	483.9

1981

L	456.9	462.0	467.1	472.3	477.6	483.0	483.5	494.0	499.7	505.4	511.2	517.6
F	473.6	479.5	485.6	491.7	497.9	504.2	510.6	517.0	523.6	530.2	536.9	543.7
U	490.8	497.8	504.8	511.9	519.1	526.4	533.7	541.1	548.6	556.2	564.0	571.7

Key : L : Lower (50% Probability) limit
U : Upper (50% Probability) limit
F : Forecasts from the identified Box-Jenkins model
DB & E F : Davies Belfield and Everest forecasts

Table 6.13 Forecasts of Dept. of Trade & Industry's Materials Indices for 1980 & 1981, using Box-Jenkins (1,1,0) ARIMA Model

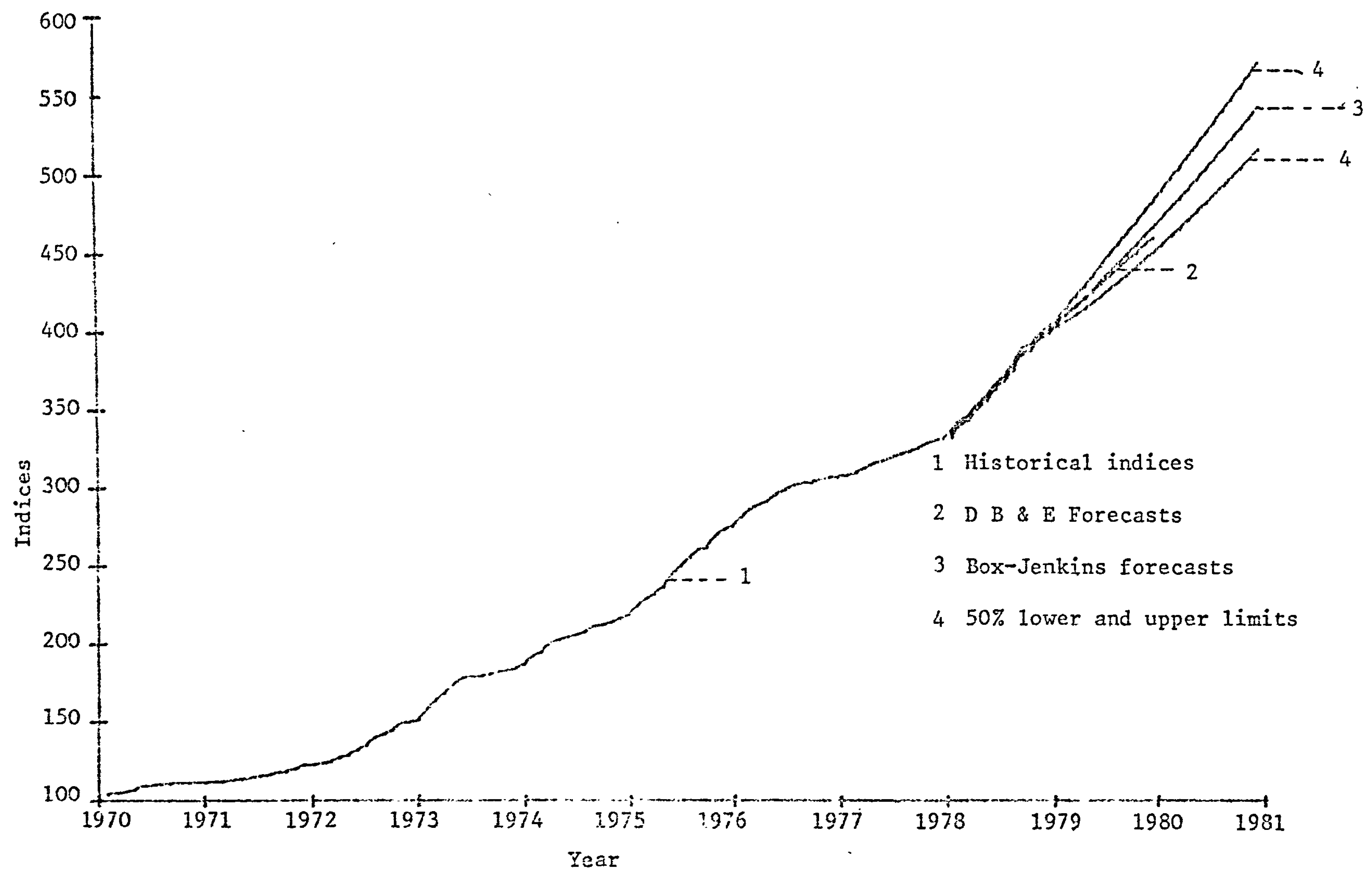


Fig 6.22 Forecasts of Department of Trade and Industry's Materials Indices 1979-81 using Box-Jenkins (1,1,0) ARIMA model (Base 1970 = 100)

Quarter / Year	1st Quart.	2nd Quart.	3rd Quart.	4th Quart.	Annual Average
1966	76.5	78.1	79.1	80.2	78.5
1967	80.2	81.3	82.4	84.0	82.0
1968	85.6	86.6	87.2	88.8	87.1
1969	89.3	89.8	91.4	92.5	90.8
1970	96.8	99.6	100.7	102.9	100.0
1971	105.0	109.0	110.0	111.0	108.8
1972	112	113	119	132	119
1973	134	136	143	147	140
1974	153	163	172	176	166
1975	189	199	215	218	205.3
1976	224	237	250	257	242.0
1977	264	271	280	282	274.3
1978	284.3	288.8	306.2	311.4	297.7
1979	317	325	360	369	342.8

DB & E Quarterly Building Cost Indices (Base 1970=100)

Table 6. 14

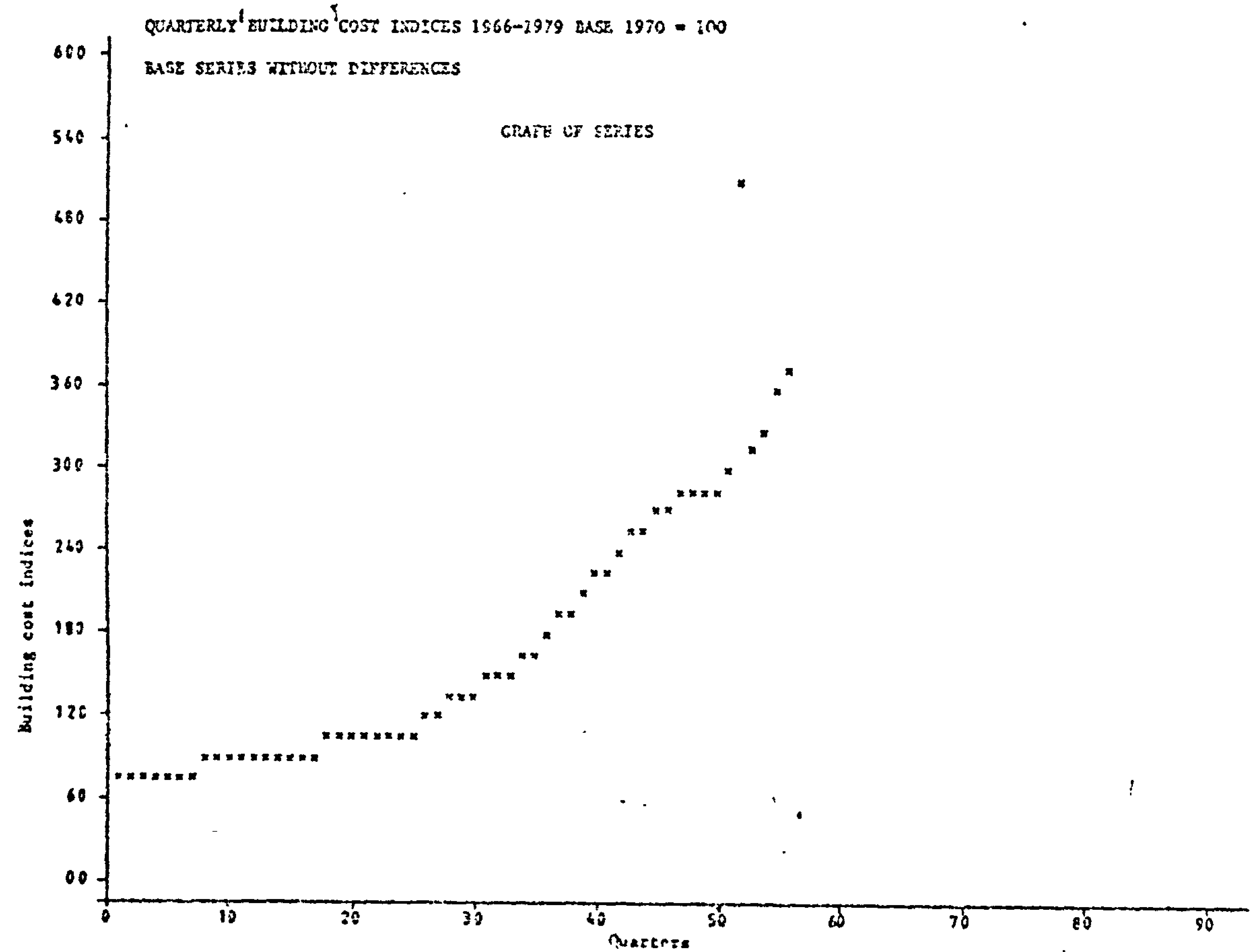
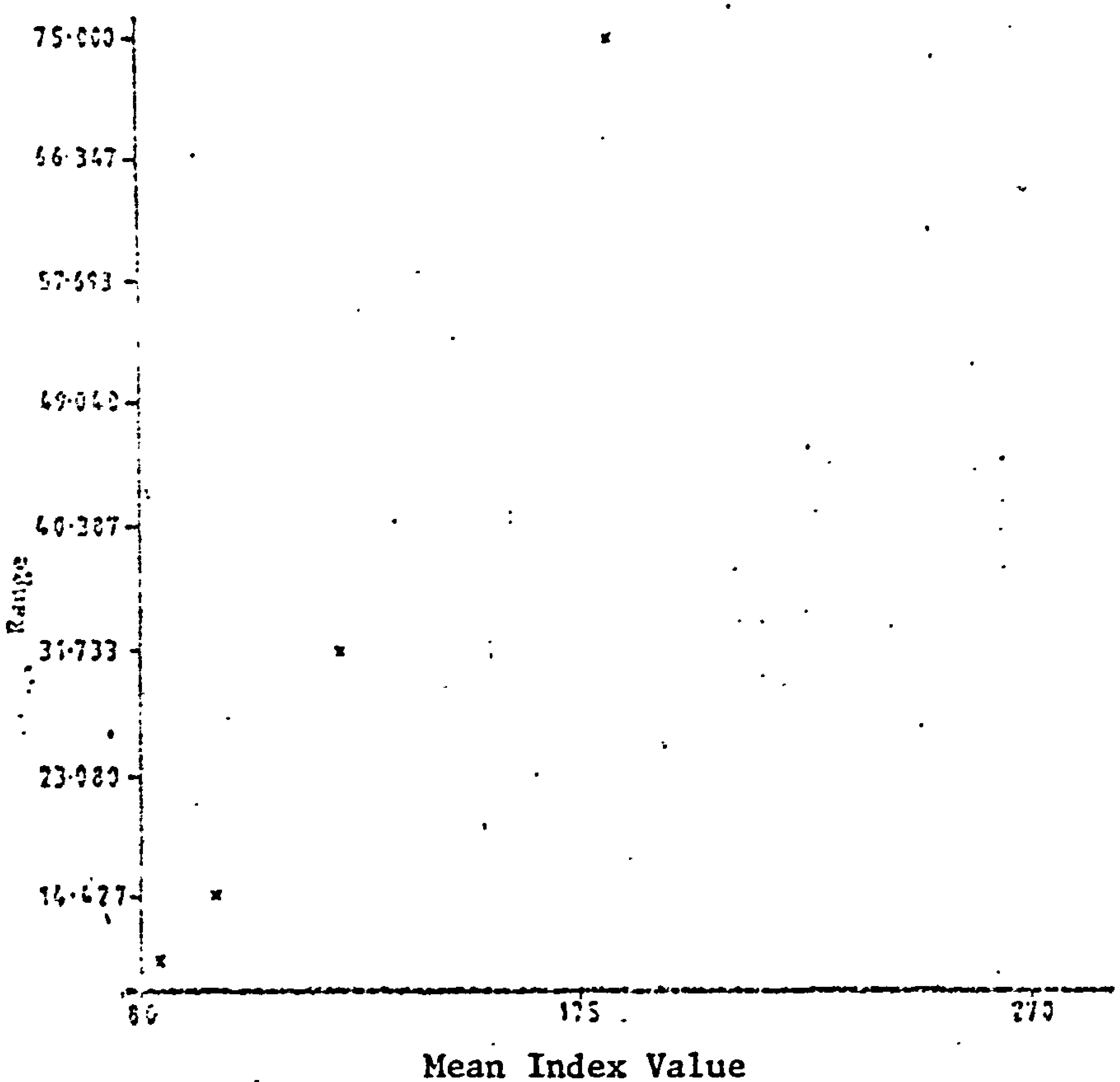


Fig 6.23 DaviesBelfield & Everest Quarterly Building Cost Indices

QUARTERLY BUILDING COST INDICES 1966-79

BASE SERIES WITHOUT DIFFERENCING

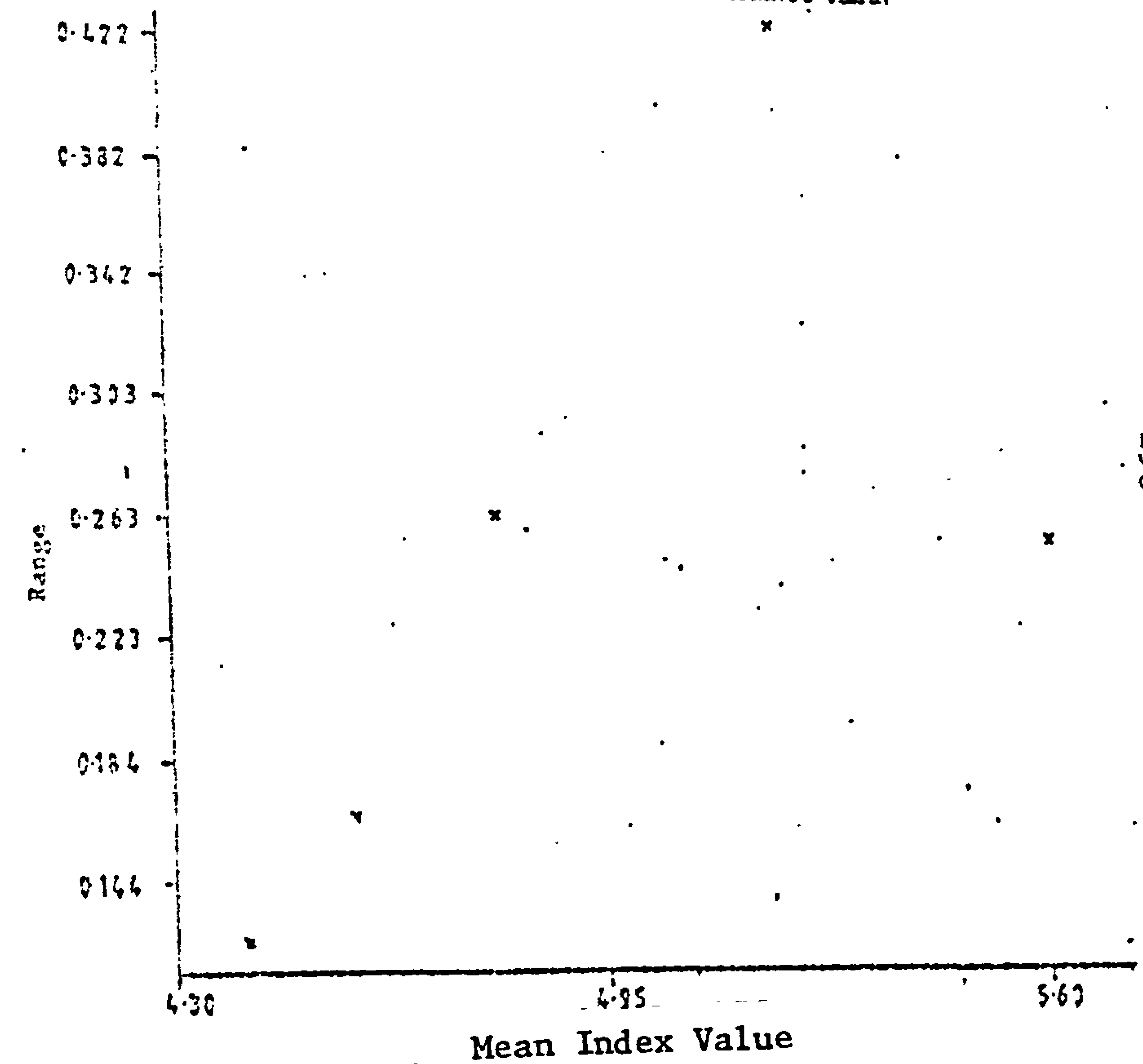


(d)

QUARTERLY BUILDING COST INDICES 1966-1979

TRANSFORMED SERIES WITHOUT DIFFERENCING

GRAPH OF RANGE AGAINST MEAN



(b)

Fig 6.24

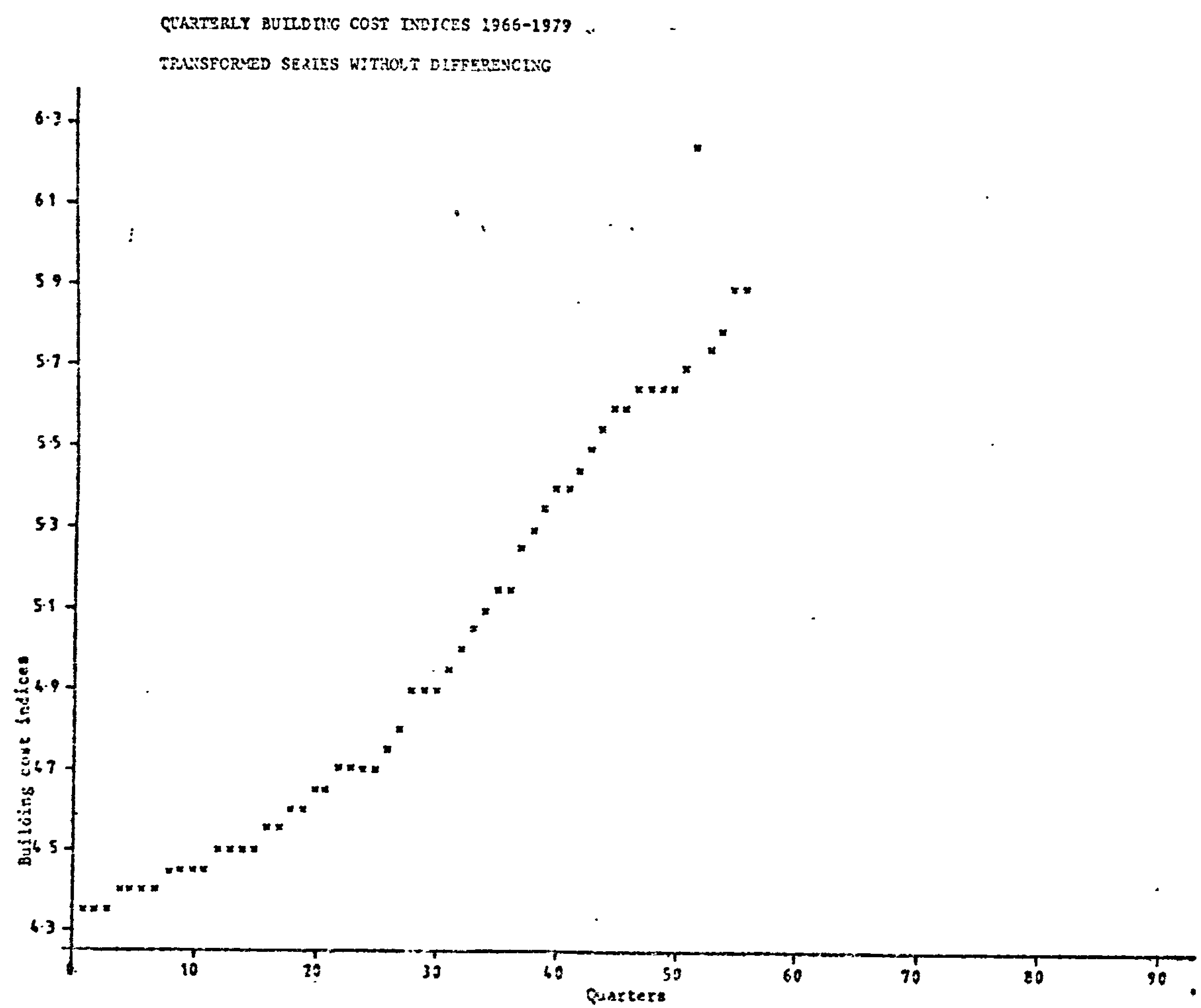

QUARTERLY BUILDING COST INDICES 1966-1979
TRANSFORMED SERIES WITHOUT DIFFERENCING
Building cost indices
6·3
6·1
5·9
5·7
5·5
5·3
5·1
4·9
4·7
4·5
4·3
0
10
20
30
40
50
60
70
80
90
Quarters

Fig 6.25

lag	autocorrelation	Partial autocorrelations
0	1	
1	0.939	0.939
2	0.892	0.087
3	0.854	0.056
4	0.811	-0.034
5	0.736	-0.0306
6	0.688	0.14
7	0.642	-0.008
8	0.595	0.009
9	0.546	0.024
10	0.495	-0.175
11	0.442	-0.020
12	0.39	-0.042

Approximate standard error $1/\sqrt{n} = 0.134$

Chi-squared statistic = 321.41

for 12 degrees of freedom

Quarterly Building Cost Indices 1966-79

Autocorrelations and partial autocorrelations of the transformed series without differencing.

Table 6.15


QUARTERLY BUILDING COST INDICES 1966-1979
TRANSFORMED SERIES WITHOUT DIFFERENCING
GRAPH OF AUTOCORRELATION FUNCTION
Autocorrelation
2SE
lag
QUARTERLY BUILDING COST INDICES 1966-1979
TRANSFORMED SERIES WITHOUT DIFFERENCING
GRAPH OF PARTIAL AUTOCORRELATION FUNCTION
Partial autocorrelation
2SE
lag

Fig. 6.26

QUARTERLY BUILDING COST INDICES 1966-1979

GRAPH OF TRANSFORMED SERIES WITH FIRST DIFFERENCING

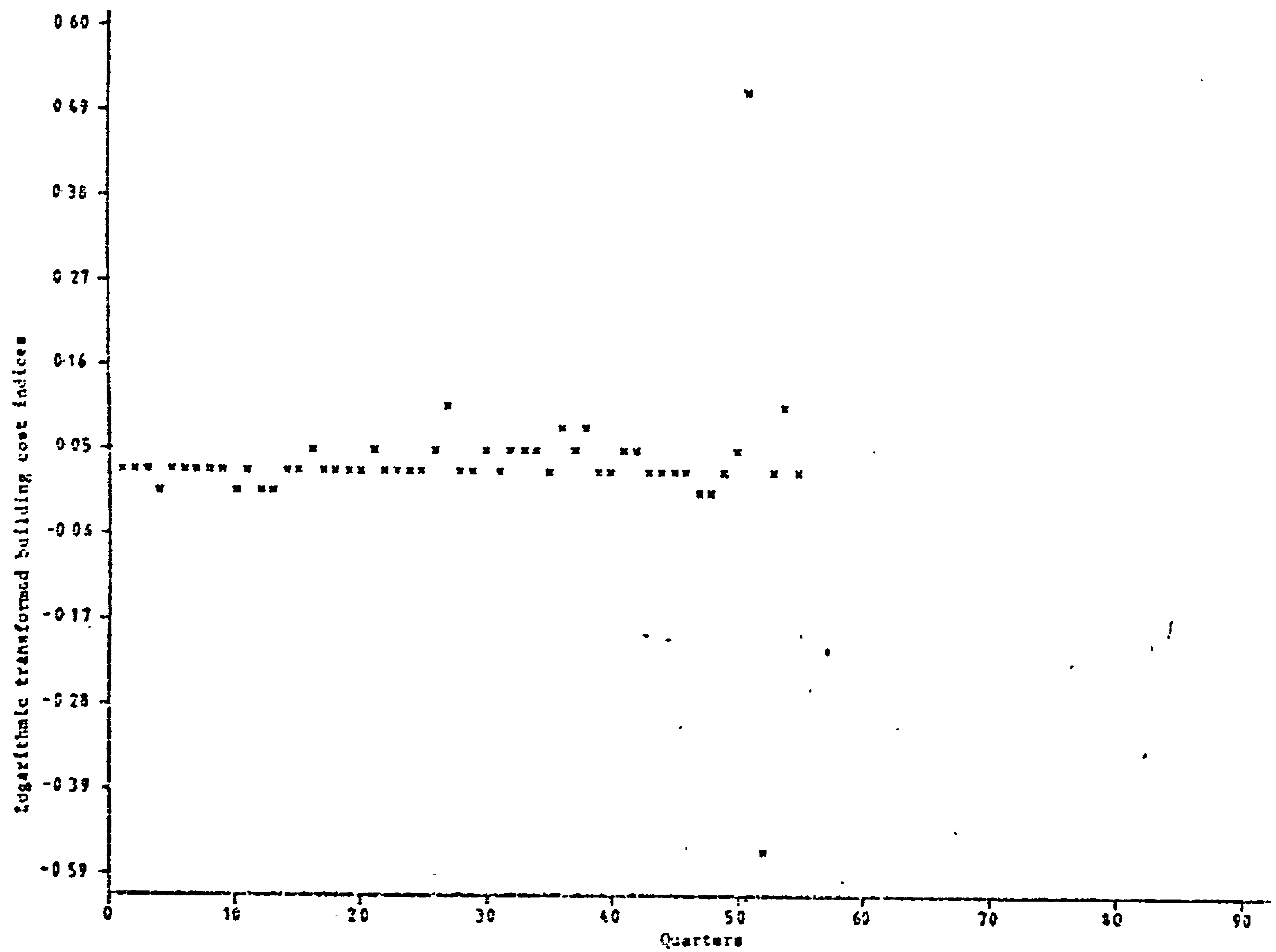


Fig 6.27

lag	autocorrelation	Partial autocorrelation
1	-0.422	-0.422
2	-0.116	-0.357
3	0.073	-0.2
4	0.014	-0.113
5	0.033	0.002
6	0.003	0.06
7	0.004	0.093
8	0.007	0.1
9	0.030	0.129
10	0.008	0.133
11	-0.021	0.087
12	-0.011	0.022

Approximate standard error $1/\sqrt{n} = 0.135$

Chi-squared statistic = 10.96

for 11 degrees of freedom

Quarterly Building Cost Indices 1966-79

Autocorrelations and partial autocorrelations of the transformed series with first differencing

Table 6.16


QUARTERLY BUILDING COST INDICES 1966-1979
TRANSFORMED SERIES WITH FIRST DIFFERENCING
GRAPH OF PARTIAL AUTOCORRELATION FUNCTION
Partial autocorrelations
lag
QUARTERLY BUILDING COST INDICES 1966-79
TRANSFORMED SERIES WITH FIRST DIFFERENCING
GRAPH OF AUTOCORRELATION FUNCTION
Autocorrelation
lag
2SE

Fig. 6.28

1978-79	1st Q 78	2nd Q 78	3rd Q 78	4th Q 78	1st Q 79	2nd Q 79	3rd Q 79	4th Q 79
L	284.0	286.4	291.9	312.3	314.7	322.3	328.7	370.8
F	288.8	290.8	296.4	317.2	319.6	327.3	333.8	376.6
Actual	284.0	288.8	306.2	311.4	318.5	325.0	360.0	369.0
U	293.3	295.3	301.0	322.1	324.5	332.4	339.0	382.4

1980-82	IQ 80	IIQ 80	IIIQ 80	IVQ 80	IQ 81	IIQ 81	IIIQ 81	IVQ 81	IQ 82	IIQ 82	IIIQ 82	IVQ 82
Lower 50%	375.0	382.2	397.2	406.7	416.7	426.9	437.7	448.8	460.3	472.1	484.3	
F	388.9	400.5	412.2	424.2	436.4	449.1	462.1	475.5	489.2	503.4	518.0	
DB & E forecasts	376.0	383.0	417.0	424.0	413.0	438.0	472.0					
Upper 50%	398.5	413.2	427.7	442.3	457.2	472.3	487.8	503.7	520.0	536.8	543.9	

Key : L : Lower (50%Probability) Limit F : Forecasts from the identified Box-Jenkins model

U : Upper (50%Probability) Limit DB & E F : Davis Belfield & Everest forecasts

Table 6.17 Forecasts of DB & E Quarterly Building Cost Indices by Box-Jenkins (1,1,0) ARIMA models

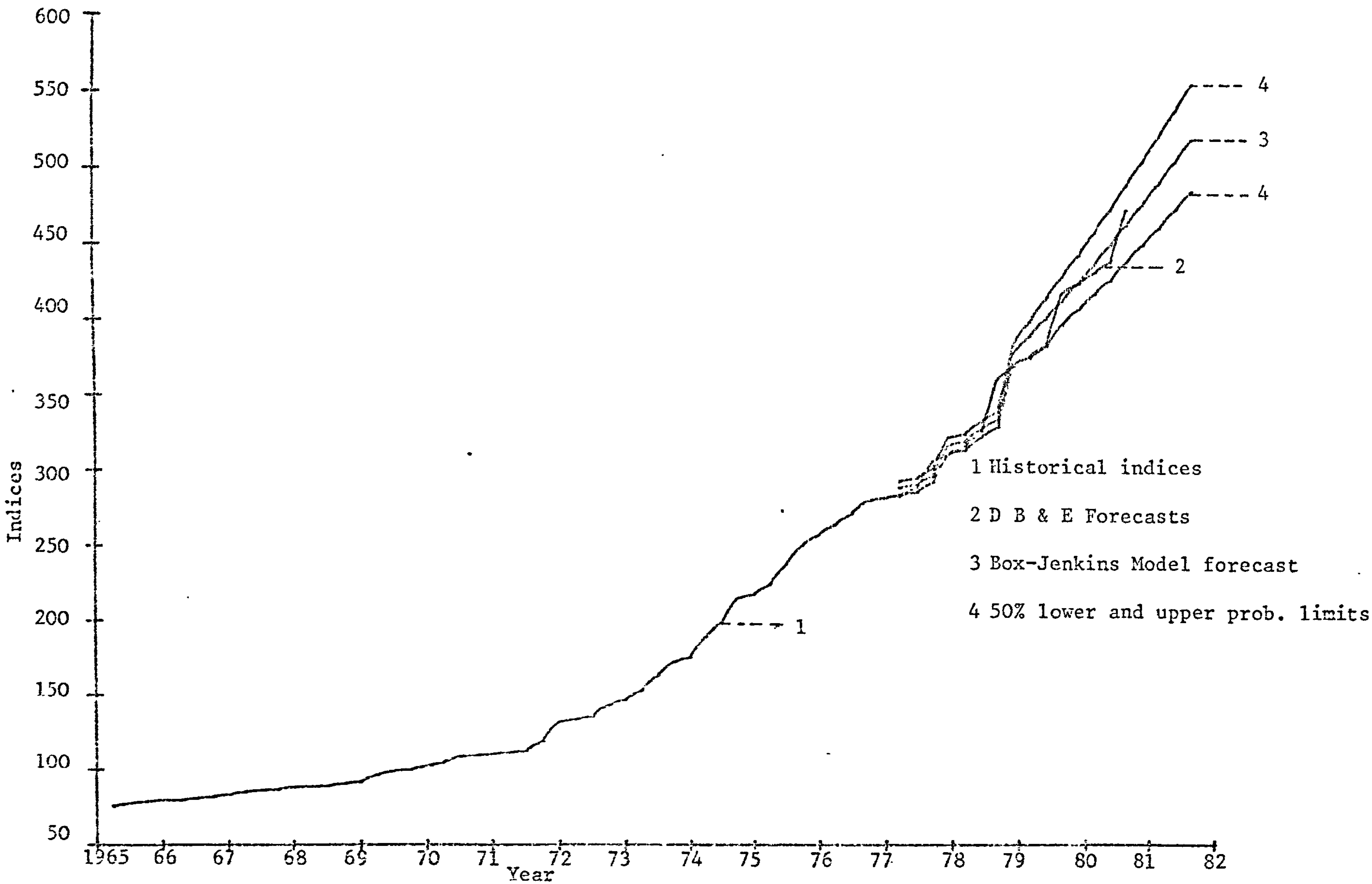


Fig 6.29 Forecasts of D B & E Quarterly Building Cost Indices 1978-82 (Base 1970 = 100) using Box-Jenkins (1,1,0) ARIMA model

6.4 Conclusions

It would appear from the survey of current literature on building cost and tender price indices forecasting, that rule of thumb methods are usually used in the construction industry. Due to the wide use of these indices for approximate cost estimating of a future facility it is felt that it is more appropriate to use a well established forecasting technique. One such technique (Box-Jenkins) has been employed in the present study. Most of the time series methods depends on the past values of the series. In this study univariate stochastic Box-Jenkins models have been used.

Forecasts from the identified Box-Jenkins Univariate Stochastic models for materials and building cost indices approximate to actual values quite well and much better than the rule of thumb methods. Since the labour indices are affected by the wage increases usually awarded in July of a given year, this causes a discontinuity in the series values; the series then remains relatively constant until the next increase in wages. For these reasons forecasts from the identified Box-Jenkins Univariate Stochastic model for labour indices are not as good as the materials indices. It would appear that more accurate forecasts for labour indices could be obtained by using Box-Jenkins intervention models.

Univariate Stochastic models are the simplest of the Box-Jenkins class of models and depends only on the past values of the series. It would appear that further accuracy in the forecast could be obtained by adjusting the univariate forecasts subjectively as necessary or alternatively by using more refined models of the Box-Jenkins class such as transfer function models (multiple input, single output), intervention models, or multivariate models (multiple out); transfer function models can take account of the variables which influence the output variable. It is therefore feasible to obtain reliable Building Cost Indices by inputting labour and materials indices. Similarly materials indices can be obtained by inputting the time series of some of the key materials indices; tender price indices could be obtained by using building cost indices as input. Intervention models can take account of factors such as increase in wages, strikes and changes in government policies. Multivariate models can be used to study the effects of different input series on selected output series.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

This chapter contains general conclusions drawn through the present research. Areas requiring further investigation are also proposed.

7.1 Conclusions

The following conclusions are drawn from the study.

1. It appears from the survey of current literature on the subject that there is no one right system, or form of organisation, or a set of techniques and procedures that can fulfill the requirements of every project. Choices have to be made according to the particular needs or situation of a project. Usually the requirements for managing, estimating and controlling a project differ from one stage to another. However, some useful approaches and techniques, as discussed in chapter 2, can be effectively applied at the various stages of a project.

2. Due to the increase in size and complexity of modern engineering and construction project, the classical management organisation structures do not seem to be suitable for the effective management and utilization of resources of a project. A project management organisation or a matrix type of organisation structure is reported to be very useful for the management of these ventures.

3. It has been demonstrated that project expenditure in cumulative form takes the shape of an S-curve. Thus S-curves or Progress Curves are widely used in the planning and control of time, cost and resources of a project. Two mathematical models were adopted to fit expenditure data for a number of projects. Both the models have provided a reasonably good fit for most of the projects. The predicting accuracy of the two models is also compared. In general Keller-Singh model has provided a better fit

for a number of projects and has given better expenditure/efforts forecasts. A set of standard parameters according to cost-category of projects is obtained for the two models, which can be used to forecast initial expenditure for similar future projects.

4. Construction cost indices are widely used for a number of puposes in the construction industry. It is shown that the Box-Jenkins methodology provides reasonable models for forecasting labour, materials and building cost indices. The forecasts from the Box-Jenkins models are in agreement with actual values. These indices can be used to forecast an initial cost estimate for a future facility.

5. Probabilistic analysis of different activities for a housing project indicated that the Weibull, Gamma, Lognormal and Normal probability distributions provide reasonable fits to the completion time data of the individual activities and overall project. However, in general the Weibull distribution gives better representation of these activities. The completion time distribution can be used for assessing progress of different activities of a project and/or sub-contractors. It can also be used for the quantitative analysis of uncertainty and assessment of risk and penalties.

6. Many projects are still controlled less effectively than they could be. Reason arises from the deficiencies and gaps in the project management systems. It has emerged from the analysis of a questionnaire survey on Systems Gaps that most important gaps

in the present systems occur between cost and time and work breakdown packages and cost codes. If these aspects are thought systematically, control systems would be greatly simplified by this action alone. Much of the activity in obtaining management level information for decision making is in obtaining, then reconciling data.

7. It was also found from the analysis of questionnaire survey that clients are time oriented and contractors cost oriented. Another observation from the analysis show that a very few organisations attempt to incorporate risk and uncertainty techniques (even such as PERT) in their planning and control operations.

7.2 Recommendations for further research

It is proposed that the following further studies be undertaken.

1. As demonstrated in fig. 1.1, further research should be directed to coordination and control aspects of contruction management.

2. It would be of interest to carry out research on the determination of optimum level of detail in cost estimation of a project as discussed in Section 2.1.5.

3. Additional research needs to be carried out to introduce and develop probabilistic models and concepts in estimation, planning and control.

4. S-curve models described in chapter 4 should be applied for manpower planning and other related areas as described in Section 4.1.3.

5. Other forecasting methods such as Adaptive forecasting and Bayesian techniques can be employed to forecast labour, materials and building cost indices. A comparison of these forecasting techniques can be made with the Box-Jenkins methodology reported in chapter 6.

6. Further work can be directed towards Box-Jenkins' other class of models such as transfer function, intervention and multivariate models.

7. Studies should be carried out to use completion Time Distribution (a) for quantifying risk and uncertainty in project cost/time, (b) for trade-off studies for the cost of extra resources and reduced risk of penalties, (c) in quantifying the risk in measure of investment worths when the activity time of a project are uncertain.

8. There is a need to carry out in depth studies for the problems, deficiencies and gaps as reported in chapter 3.

Appendix A

A guide for selecting a contract type

Type of contract	Requirements for use	Advantages	Disadvantages	Applications	Remarks
1. Lump sum contract	Complete plans, specifications. Scope of work well defined	1. Maximum construction efficiency (minm. time: minm. cost) 2. Owner assured of quality as described in detailed project specifications 3. Cost predetermined to the owner	1. Separate contracts for design and construction increase overall project schedule 2. Noncompetitive design may result in overconservative design basis 3. Responsibility is divided between designer and contractor 4. Competition of efficiency plus mark-up and not of performance	1. Buildings designed by architects and constructed through LS contracts	Claims and difficulties if project not well defined Changes difficult to make Presence of conflict between the interest of the owner and the contractor Intangible incentive for consultant, job well done
2.A. Unit price, flat rate	Complete plans, specifications. Scope of work well defined, approximate quantities known	1. Construction work can commence without knowing exact quantities involved 2. Reimbursement terms are clearly defined 3. Removes element of risk and higher costs	1. Large quantity estimate errors may result in client's paying unnecessarily high unit costs or contract extra 2. Extensive client field supervision is required to measure installed quantities	1. Gas transmission piping project 2. Highways 3. Insulation work in process plants 4. Dredging 5. Engineering construction in which full extent of work cannot be defined at commencement of work	

Type of contract	Requirements for use	Advantages	Disadvantages	Applications	Remarks
B. Unit price, sliding rate	Complete plans and specifications. Scope of work well defined, approximate quantities known	1. Construction work can commence without knowing exact quantity requirements 2. Reimbursement terms are clearly defined 3. Less chances of claims in case of modifications and/or escalation	1. Extensive client field supervision is required to measure installed quantities	1. Gas transmission piping project 2. Highways 3. Insulation work in process plants 4. Dredging	
3. Project management	General scope of project initially on selection of PM, after which development of detailed scope of work and budget prior to implementation	1. Permits effective communication 2. Gives flexibility to overcome the unexpected 3. Efficient use of joint expertise 4. Construction can overlap with design 5. Sequential tendering makes expenditure control easier 6. Payment to sub-	1. Difficulty of selecting suitable individual or people as project manager 2. Unwillingness of the owner to give total authority to project manager 3. Conflict of interest if PM has stake in design or construction 4. Reluctance of some consultants to discard traditional role 5. Difficulty in obtaining mutual respect for	1. Any large project where time and cost are important	Project manager's remuneration should be based on performance (although as a professional he does not like it)

Type of contract	Requirements for use	Advantages	Disadvantages	Applications	Remarks
		contractors on completion of their work	abilities of various parties to the project		
		7. High cost of extras reduced	6. Difficulty in forecasting final cost		
4. Construction management		(Similar to Project Management)			Construction manager does not have to be selected until working drawings prepared
5. Turn key A. Build to lease B. Build to purchase C. Build to lease-purchase	Performance type technical specifications, preliminary layouts, drawings	1. Competitive engineering design often results in cost reducing features 2. Reduces overall project time by overlapping design and construction 3. Single party responsibility leads to efficient project execution 4. Allows contractor to increase profit by superior performance	1. Contractor's proposal cost is higher 2. Fixed cost is based on preliminary drawings 3. Contract and proposal require careful and lengthy client review, hence the client is paying for technical staff twice	1. Turnkey contract to design and construct fertilizer plant 2. Turnkey contract to design and construct foreign power generating plant	Bids should be solicited only from contractors experienced in particular field Client should review project team proposed by contractor

Type of contract	Requirements for use	Advantages	Disadvantages	Applications	Remarks
6.A. Cost plus	Scope of work does not have to be clearly defined	1. Eliminates detailed scope-definition and proposal- preparation time 2. Eliminates costly extra negotiations if many changes are contemplated 3. Allows client complete flexibility to superyise design and/or construction	1. Client must exercise tight cost control over project expenditure 2. Project cost is usually not optimized	1. Major revamping of existing facilities 2. Development projects where technology is not well defined 3. Confidential projects where minimum industry exposure is desired 4. Used where impossible to determine extent of work 5. Projects where minimum time schedule is critical	Cost-plus contracts should be used only where client has sufficient engineering staff to supervise work Design not done by contractor
B. Cost-plus with guaranteed maximum cost	General specifications and preliminary layout drawings	1. Maximum price is established 2. Client retains option to approve all major project decisions 3. All savings under maximum price remain with client	1. Contractor has little incentive to reduce cost 2. Contractor's fee and contingency is relatively higher than for other fixed-price contracts because price is fixed on preliminary design data	1. Where client desires fast time schedule with a guaranteed limit on maximum project cost 2. Construction management contracts	

Type of contract	Requirements for use	Advantages	Disadvantages	Applications	Remarks
			3. Client must exercise tight cost control over project expenditures		
C. Cost-plus with guaranteed maximum cost and incentive	General specifications and preliminary layout drawings	1. Maximum price is established without preparation of detailed design drawings 2. Client retains option to approve all major project decisions 3. Contractor has incentive to improve performance since he shares savings	1. Contractor's fee and contingency is relatively higher than other fixed price contracts because price is fixed on preliminary design data	1. Where client desires fast time schedule with a guaranteed limit on maximum cost, and assurance that the contractor will be motivated to try for cost savings	Incentive may be provided to optimize features other than capital cost - e.g. operating cost
7. Convertible contracts	General scope of project	1. Design work can commence without delay of soliciting competitive bids 2. Construction price is fixed at time of contract conversion when project is well defined	1. Design may not be optimum 2. Difficult to obtain competitive bids since other contractors are reluctant to bid against the contractor who performed the initial work	1. Where client has confidential project requiring a balance of minimum project time with reasonable cost (one component to be manufactured) 2. When client selects particular contractor based on superior past	Contractors selected on this basis should be well known to clients

Type of contract	Requirements for use	Advantages	Disadvantages	Applications	Remarks
				performance (machinery foundations contractor)	
8. Time and materials	General scope of project	1. Client may exercise close control over contractor's execution methods 2. Contractor is assured of reasonable profit 3. Reimbursement terms are clearly defined	1. Project cost may not be minimized 2. Extensive client supervision is required	1. Management engineering services supplied by consulting engineering firms 2. Repair jobs in factories where space is a constraint 3. Additions and alterations for which no plans have been developed	Eliminates lengthy scope definition and proposal preparation time Design and construction done by one party

Appendix B

A guide on the selection of computer programs available for Project Management

Table of Computer Programs

Computer configuration	Source	Program name	Application	Comments
Burroughs computers	Burroughs business machines	PROMIS	Network processing and analysis	Programmed in COBOL consists of three modules - time, cost, and resources
CDC/6000 and CYBER 70	Cybernet services	PERT/TIME	Planning, monitoring, and evaluating the status of a project	It utilizes a time-oriented network structure. Handles up to 800 activities and 6000 events
CDC/6600	Multiple Access General Computer Corporation	Project/Costing System	Time/cost analysis and employee performance reporting	Produces up-to-date information on the progress and cost of a project; manpower efficiency can be monitored
	Multiple Access General Computer Corporation	Project Management and Control Systems (PMCS)	Planning, scheduling, and controlling large, complex projects.	Processes and reports both time and cost information; it handles up to 1500 activities and 1800 events
IBM/360/Os	Mcdonnel Douglas Automation Co.; 500 Jefferson Bldg.; Houston, Texas 77002	Management Scheduling and Control System (MSCS)	CPM, precedence, scheduling and resource leveling	A multiproject system for scheduling and resource leveling; specially tailored report formats possible.

Computer configuration	Source	Program name	Application	Comments
IBM/360,370,OS	International Business Machines (IBM)	Project Management System (PMS) IV		A large scale project scheduling and control package designed for the IBM/370 computer system. The user selects the type of processing required from the first three processors and produces the relevant reports using the fourth processor
		a. PMS Network Processor	CPM/Precedence/PERT (without probability)	
		b. PMS Resource Allocation Processor	Resource allocation	
		c. PMS Cost Processor	Cost analysis	
		d. PMS Report Processor	Report generation	
IBM/370, 370, OS/VS IBM DOS/VS		Project Analysis and Control System (PROJACS)	CPM, Precedence resource allocation, cost control	It has a main processor which calls upon three other processors, Network Preparation, Resource Allocation and Cost Evaluation. It can store standard networks which can be used for preparing a project network. It also prints precedence diagrams. It can function in interactive mode.
IBM/1130 IBM/360, 370 OS, DOS	IBM	Project Control System (PCS)	Network processing resource allocation, cash flow	Similar to PMS; however somewhat simpler in concept

Computer configuration	Source	Program name	Application	Comments
IBM-APL/360, OS OY DOS, T.S.O.	IBM	Minipert	PERT (without probability), resource allocation	Allows "hands-on" input/output via console teletype
IBM/370, OS	IBM	"Linear Programming System/370"	Linear programming (optimization)	Uses the simplex method of linear programming
IBM/370, OS	IBM	"General Purpose Simulation System"	Simulation	Problem-oriented language, based on queuing theory, generates statistics for queues and facilities
IBM/1130	U.S. Public Buildings Service	"Construction Management Control System"	CPM, cost analysis, material expediting, financial analysis	An integrated system for schedule reports, cost reports, financial reports, purchase order control, and progress billing
GE-200	General Electric	CPM/PROMOCOM	Network processing, cost analysis	Both "normal" and "crash" activity times and costs can be input, to obtain a time-cost tradeoff
GE-Mark II	General Electric	"Linear Programming"	Linear programming (optimization)	Uses the two-phase simplex method, also performs sensitivity analysis on the parameters
GE-Mark II	General Electric	General Purpose Systems Simulator	Simulation, modeling	Permits study of logical structure, flow of traffic and competition for resource in a system

Computer configuration	Source	Program name	Application	Comments
GE-Mark II	General Electric	Inventory Control	Inventory control	Serves as generalized order processing and finished inventory control system
IBM/370, DOS	IBM	PACIFIC/370		
		a. Estimating Module	Estimating	An integrated system for estimating and billing for progress payments on unit price contracts, and cost control
		b. Work Measurement and Billing Module	Work measurement and billing	
		c. Cost Control Module	Cost control	
IBM/370, OS	Project Software and Development, Inc.	Project-II	CPM/Precedence, resource allocation, cash flow, time and cost control	Problem-oriented language for project managers Scheduling control, cost, and resource management problems
IBM/370, OS	Massachusetts Institute of Technology	ICES OPTECH-1	Optimization techniques	Time/cost trade-off problems using linear programming
IBM/1130	IBM	Construction Estimation Program	Estimating	Performs necessary extensions to the users take-off, specification and cost data, and estimates
GE-625/635	General Electric	PERT/Time	PERT (without probability)	Produces PERT schedule

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IN

ORIGINAL

Computer configuration	Source	Program name	Application	Comments
GE-600	General Electric	PERT/Cost	Cost analysis	Produces cost control reports based on PERT time data
GE-Mark II	General Electric	Capital Equipment Investment Analysis	Analysis of alternatives to purchasing new equipment	Using Monte Carlo simulation, this program simulates the cash outflow resulting from different production alternatives
GE-Mark II	General Electric	Force Scheduling System	Manpower scheduling	A package of four programs capable of scheduling a work force that provides continuous, uninterrupted service
	Purdue University, Lafayette, Indiana	GERTS Simulation Programs	GERT analysis	The program is written in Fortran IV and is completely self-contained; therefore it can be run on any system that has a Fortran compiler
GE-400	General Electric	CPM/Project Monitor and Control System	CPM analysis	Creates network schedules and allows updating as the project progresses

Appendix C

C1 List of members of the Internet (U.K.) working group on Systems Gaps

C2 Questionnaire form used for the Survey Analysis

C3 Analysis of Survey on Systems Gaps

C4 Differences in Practice of Management and Behaviour of Client and Contractor Oriented Projects

Appendix C1

C1 List of Members of the Working Group on Systems Gaps

1. Mr R Baker

   Computel Limited

2. Mr C Castell

   British Gas Corporation, Transmission Planning

3. Mr R Croissant

   Computation Research & Development

4. Mr E Gabriel

   Chairman, Internet Working Group, Foster Wheeler Ltd.

5. Dr M Bissett

   Arthur Anderson & Co.

6. Dr A Z Keller

   Chairman, Postgraduate School in Industrial Technology

   University of Bradford

7. Mr D Rogers

   B.N.O.C.

8. Mr R Harris

   W S Atkins & Partners, Project Management Services

Appendix C2

'The Project Manager', October, 1979

THE ASSOCIATION OF PROJECT MANAGERS

WORKING PARTY - THE SYSTEMS GAP

QUESTIONNAIRE ON CURRENT PRACTICE

Please complete with respect to a typical major project undertaken by your organisation and return to:-

Systems Gap Working Party,
c/o Internet (UK) Secretariat,
The Association of Project Managers,
108, Horseferry Road,
London. SW1P 2EF.

by 30th November, 1979, if possible.

Thank you for your co-operation.

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IN

ORIGINAL

Please complete by ringing the appropriate answer to each question.

THE SYSTEMS GAP - QUESTIONNAIRE

1. ORGANISATION

1.1. What is your relationship to the project?

OWNER/CONTRACTOR

1.2. What is the project cost (£m)?

UNDER 1 / 1-5 / 5-25 / OVER 25

1.3. What is the project duration (Months)?

UNDER 6 MONTHS / 6 MONTHS - 1 YEAR / 1 YEAR - 3 YEARS / OVER 3 YEARS

1.4. Where is the project site?

UK / DEVELOPED COUNTRY / THIRD WORLD

1.5. Where is the project manager located during the design and procurement phase?

HOME OFFICE / SITE

1.6. AND, during the construction phase?

HOME OFFICE / SITE

1.7. To whom is the project manager responsible?

PROJECT DIRECTOR / OPERATIONS DIRECTOR /
MANAGING DIRECTOR / OTHER (SPECIFY)

1.8. What were the maximum numbers (full-time equivalent) of the following disciplines working on the project?

	DESIGN		CONSTRUCTION	
	HOME OFFICE	SITE	HOME OFFICE	SITE
PLANNERS				
COST ENGINEERS				
ADMINISTRATION				
DESIGN/PROJECT ENGINEERS				
MATERIALS CONTROLLERS				
CONTRACT ADMINISTRATORS				

9. Were temporary/agency staff employed on the project?

YES / NO

10. IF YES, what were the reasons?

- WORK OVERLOAD
- UNABLE TO OBTAIN PERMANENT STAFF
- TO OBTAIN SKILLS NOT EXISTING WITHIN THE ORGANISATION
- OTHER (SPECIFY)

11. ALSO IF YES, how effectively did the temporary staff work relative to equivalent permanent staff?

SAME / BETTER / WORSE.

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IN

ORIGINAL

2. WORK BREAKDOWN

2.1. How many work breakdown structures are in use?

1 / 2 / 3 / OVER 3

2.2. What was the basis for the major work breakdown?

COST CODES / PHYSICAL WORK PACKAGES /
DISCIPLINES / GEOGRAPHIC AREAS / OTHER (SPECIFY)

2.3. How many levels are there in the major work breakdown?

1 / 2 / 3 / 4 / OVER 4

2.4. How many cost control categories are there in each level?

	UNDER 10	10-30	30-100	OVER 100
LEVEL 1				
LEVEL 2				
LEVEL 3				
LEVEL 4				

2.5. At what level is there a link between the work breakdown structure, used for cost control, and that used for progress control?

NON / SUMMARY / INTERMEDIATE / DETAIL

2.6. Are project commitment budgets made before cost commitments are entered into?

ALWAYS / USUALLY / SOMETIMES

3. DATA VOLUMES

3.1. What is the maximum number of activities on a single network?

UNDER 100 / 100 - 500 / 500 - 1,000 / 1,000 - 5,000/ 5,000 - 10,000 / OVER 10,000

3.2. How many levels are there in the project plan?

1 / 2 / 3 / 4 / OVER 4

3.3. How many activities are there at each level of the project plan in total?

	UNDER 100	1-500	500-1,000	1,000 - 5,000	5,000 - 10,000	OVER 10,000
LEVEL 1						
LEVEL 2						
LEVEL 3						
LEVEL 4						
LOWEST LEVEL						

3.4. What is the update/review period for progress?

DAILY / WEEKLY / FORTNIGHTLY / MONTHLY / QUARTERLY / OTHER (SPECIFY)

3.5. What is the maximum number of work packages for cost control?

UNDER 100 / 100-500 / 500-1,000 / 1,000-5,000 / OVER 5,000

3.6. What is the update/review period for costs?

WEEKLY / FORTNIGHTLY / MONTHLY / QUARTERLY / OTHER (SPECIFY)

3.7. What is the time delay between the data cut-off date and report issue for cost control?

UNDER 3 DAYS / 3 DAYS - 1 WEEK / 1 WEEK - 2 WEEKS / 2 WEEKS - 1 MONTH / OVER 1 MONTH

3.8. AND FOR progress control?

UNDER 3 DAYS / 3 DAYS - 1 WEEK / 1 WEEK - 2 WEEKS / 2 WEEKS - 1 MONTH / OVER 1 MONTH

4. DATA CAPTURE

4.1. Is the information used for updating time and costs -

INDEPENDENT / RELATED?

4.2. How is update information obtained for the project network(s)?

REVIEW MEETING / PROGRESS CHASING / COMPUTER-PRODUCED SCHEDULE / PRO-FORMA RETURN / OTHER (SPECIFY)

4.3. AND FOR, cost data?

REVIEW MEETING / PROGRESS CHASING / COMPUTER-PRODUCED SCHEDULE / PRO-FORMA RETURN / OTHER (SPECIFY)

4.4. Are records kept of historical progress information?

YES / NO

4.5. Are records kept of historical resource usage?

YES / NO

4.6. Are records kept of historical cost information?

YES / NO

5. PLANNING METHODS

5.1. Do you use computerised networks?

YES / NO

5.2. Do you use a computerised cost control system?

YES / NO

5.3. IF SO, is it linked to a computerised network?

YES / NO

5.4. Do you use a computerised procurement system?

YES / NO

5.5. IF SO, is it linked to a computerised network?

YES / NO

5.6. Is your achievement relative to planned dates typically?

EARLY / ON TIME / LATE

5.7. Is your achievement relative to budgetted costs typically?

UNDER BUDGET / ON BUDGET / OVER BUDGET

5.8. Do you attempt to recognise risk and uncertainty by using three value PERT (i.e. by estimating minimum, maximum and most likely times for project activities)?

YES / NO

5.9. Do you attempt to take account of risk and uncertainty by use of any other specialised (e.g. probabilistic) techniques?

5.10. IF SO, please specify.

6. COMPUTING

6.1. Do you use a computer system?

IN HOUSE / BUREAU / NONE

6.2. IF SO, please identify the configuration of the computer equipment you use.

MAINFRAME / MINI / OTHER (SPECIFY)

6.3. How do you input data to the computer?

PAPER TAPE / TERMINALS / PUNCH CARDS / OTHER (SPECIFY)

6.4. Please identify the type of programs used and length of time for which they have been in use for the following purposes.

PURPOSE	PROGRAM TYPE			LENTH OF USE (YRS.)
	PACKAGE	DEVELOPED IN-HOUSE	NONE	
PLANNING/NETWORKS				
COST CONTROL				
MATERIALS CONTROL				

6.7. Is data processing support provided by -

PROJECT TEAM / DP DEPARTMENT / BUREAU

6.8. Have you had formal training in the use of your network/time control package?

YES / NO

6.9. Were your computer programs chosen by -

PURPOSE	OWNER POLICY	CONTRACTOR POLICY	PROJECT MANAGER	OTHER (SPECIFY)
PLANNING/NETWORKS				
COST CONTROL				
MATERIALS CONTROL				

7. CONTINUING COLLABORATION

7.1. Would you be prepared to supply detailed planning and cost information as part of a continuing collaboration with the Systems Gap Working Party?

YES / NO

7.2. IF YES, please provide a contact name and telephone number.

Thank you for your co-operation in completing the questionnaire. It is very much appreciated.

APPENDIX C3

ANALYSIS OF INTERNET SURVEY ON SYSTEMS GAPS.

1. Organisation

1.1. Relationship to the Project (client/contractors)

50% of our sample were clients and 50% were contractors.

1.2. Cost of the projects

44% of the projects were of cost £5-25m

19% were 1-5 (£m), 31% of over £25m,

7% were under £1m.

1.3. Duration of the projects

56% of the projects were of 1-3 years.

37% were of over 3 years duration.

7% were under 6 months.

1.4. Correlation between Time and Costs

19% of the projects were of cost £1-5(m) and of duration 1-3 years.

31% of the projects were of cost 5-25 (£m) and of duration 1-3 years.

13% of the projects were of cost 5-25 (£m) and of duration of over 3 years.

7% of the projects were of cost of over £25m and of duration 1-3 years.

25% of the projects were of cost of over £25m and of duration of over 3 years.

1.5. Project site

62% of all the projects were located in U.K.

19% in developed countries.

19% in third world countries.

1.6. Location of the Project Manager

(a) during the design and procurement phase

The project managers of 81% of the projects were in

1.6. (contd.)

home office and of 19% were on site.

(b) <u>and during the construction phase</u>

56% were in home office

44% were on site.

1.7. <u>To whom is the project manager responsible?</u>

56% were responsible to the Project Director

20% to Operations Director

6% to Project Group Manager and Steering Committee

6% to Assistant Works Manager

6% to Architect

6% to Construction Engineer

1.8. <u>Temporary staff employed on the project</u>

69% employed temporary staff

31% didn't employ temporary staff.

1.9. <u>Reason for employing temporary staff</u>

25% employed due to work load

31% employed due to non-availability of permanent staff

13% employed due to non-availability of the skills within the organisation

6% fluctuating base level

25% not responded.

1.10. <u>Efficiency of the temporary staff relative to equivalent permanent staff</u>

38% found them <u>same</u> as the permanent staff

6% found <u>better</u>

25% <u>worse</u>

31% not responded.

1.11. <u>Correlation between size of the project and no. of people working</u>

1.11. (contd.)

On average 17 persons were employed for projects of costs £1-5m

On average 27 persons were employed for projects of costs £5.25m

On average 33 persons were employed for projects of costs over £25m.

1.12. Maximum numbers (full-time equivalent) of the following disciplines working on the project?

Because of the diversity of the figures given by the respondents the figures are presented in two tables according to cost-category.

Figures in first table are the average of 5 projects

Table 1.8 (a)

Cost of the projects (two) £1-5m " " " (three) £5-25m	Design		Construction	
Duration of the projects Three 1-3 yrs. " " " (two) over 3 yrs.	Home office	Site	Home Office	Site
Planners	4.8	-	+	*
Cost Engineers	1.6	-	+	+
Administration	3.8	-	0.8	1.6
Design/Project Engineers	6.2	-	0.4	-
Materials Controllers	0.8	-	+	+
Contract Administrators	0.6	-	+	+

\+ Only one respondent had one

* Only one respondent had 10

Average of 4 projects.

Table 1.8 (b)

Cost of projects over £25m duration over 3 years	Design		Construction	
	Home Office	Site	Home Office	Site
Planners	3	-	-	-
Cost Engineers	5	-	-	-
Administration	4	0.5	1	0.25
Design/Project Engineers	*	0.25	0.25	-
Materials Controllers	1.5	-	-	0.25
Contract Administrators	2	0.25	-	0.25

* Mean of two projects was 11 and of other two was 90

The following figures are for one typical project.

Project cost over £25m duration over 3 years Location Third World	Design		Construction	
	Home Office	Site	Home Office	Site
Planners	1	12	1	12
Cost Engineers	0	15	0	15
Administration	3	3	3	3
Design/Project Engineers	150	120	150	120
Materials Controllers				15
Contract Administration	5			30

Considerable overlap due to phasing

2. Work Breakdown

2.1. Work breakdown structures in use

25% use One work breakdown structure

19% use Two work breakdown structures

19% use Three work breakdown structures

37% use over Three work breakdown structures

2.2. Basis for the major work breakdown

56% Physical Work Packages

6% Cost Codes

6% Discipline

6% Geographic areas

20% a combination of the above

6% not responded

2.3. Levels in the major work breakdown

19% have One level

19% have Two levels

12% have Four levels

44% have over Four levels

6% not responded

2.4. Cost Control Categories in each level

level 1: 38% have under 10, 12% have 10-30, 6% have 30-100 & 6% over 100 Cost Control Categories

level 2: 6% have under 10, 19% have 10-30, 12% have 30-100, 6% over 100

level 3: 6% have under 10, 19% have 30-100, 6% over 100

level 4: 6% have 10-30, 12% have 30-100 and 25% have over 100.

rest not responded.

2.5. At what level is there a link between the work breakdown structure, used for cost control, and that used for progress control?

26% none

12% summary

12% intermediate

31% detailed

19% not responded

2.6. Are project commitment budgets made before cost commitments are entered into?

75% always

6% usually

19% not responded

3. Data Volumes

3.1. Maximum Numbers ofactivities on a single network

19% 100-500 activities on a single network

12% 500-1000 " " "

44% 1,000-5,000 " " "

15% 5,000-10,000 " " "

3.2. Levels in the project plan

25% One level

31% Two levels

12% Three levels

6% Four levels

7% over Four levels

19% not responded

3.3. No. of activities at each level of the project plan in total

Level 1: 44% under 100, 6% 1-500, 6% 1,000-5,000 activities

Level 2: 38% 1-500, 6% 500-1,000, 12% 1,000-5,000, 26% 5,000-10,000

Level 3: 6% under 100, 12% 1,000-5,000

Level 4: 6% 1,000-5,000

Lowest level: 6% 500-1,000

rest not responded

3.4 Update/review period for progress

19% fortnightly

75% monthly

6% bimonthly

3.5. Update/review period for costs

6% weekly

6% fortnightly

80% monthly

8% quarterly

3.6. Maximum number of work packages for cost control

44% under 100 work packages

25% 100-500 " "

6% 500-1,000 " "

25% not responded

3.7. Time delay between the data cut-off and report issue for Cost Control

31% 3 days - 1 week

19% 1 week - 2 weeks

25% 2 weeks - 1 month

6% over 1 month

19% not responded

3.8. and for progress control

12% under 3 days

38% 3 days - 1 week

19% 1 week - 2 weeks

25% 2 weeks - 1 month

6% over 1 month

4. Data Capture

4.1. Information used for updating time and costs

50% Independent

38% Related

12% not responded

4.2. Update information obtained for the project network

19% obtained by Review Meeting

31% " " Progress Chasing

19% " " Pro-forma Return

31% " " Review Meeting and Progress Chasing

4.3. Update information for cost data

25% obtained by Reveiw Meeting

19% " " Progress Chasing

19% " " Pro-forma Return

6% " " Review Meeting and Progress Chasing

19% " " Computer Produced Schedule

12% not responded

4.4. Records of historical progress information

69% keep the records

25% do not keep the records

6% not responded

4.5. Records of historical resource usage

69% keep the records

25% do not keep the records

6% not responded

4.6. Records of historical cost information

88% keep the records

6% do not keep the records

6% not responded

5. Planning Methods

5.1. Use of computerised networks

75% use computerised networks

25% do not use computerised networks

5.2. Use of a computerised cost control system

87% use a computerised cost control system

13% do not use a computerised cost control system

5.3. Use of a computerised procurement system

19% use a computerised procurement system

75% do not use a computerised procurement system

6% not responded

5.4. Is computerised cost control system linked to a computerised network

25% have it linked

75% do not have it linked

5.5. Is computerised procurement system linked to computerised network

75% do not have it linked

25% not responded

5.6. Is achievement relative to planned dates typically?

31% have on time

69% have late

5.7. Is achievement relative to budgeted costs typically?

6% report being under budget

50% report being on budget

44% report being over budget

5.8. Use of Risk and Uncertainty by PERT or any other specialised (e.g.Probabilistic) techniques?

No one reported taking account of Risk and Uncertainty by any method.

6. Computing

6.1. Use of computer systems

75% use InHouse computer system

6% use Bureau

19% use both systems

6.2. Configuration of the computer system equipment in use

69% use main frame

19% use mini

12% use both

6.3. Input of data to the computer

63% use Terminals

12% use Punch cards

25% use combination of the above

6.4. Type of Program used for

Planning/Networks: 69% use Package and 19% programs developed in house

12% not responded

Cost Control: 12% use Package and 44% programs developed in house

12% none

31% not responded

Materials Control: 6% use Package and 25% developed in house

19% none

50% not responded

6.5. Data Processing support provided by

69% by DP Dept.

19% by Project team

6% by Bureau

6% not responded

6.6. Formal training in the use of Network/time control package

63% got formal training

31% got no training

6% not responded

7.1. Continuing collaboration

44% say Yes

56% say No

APPENDIX C4

ANALYSIS OF INTERNET SURVEY ON SYSTEMS GAP

1. Organisation

Table 1.1

Relationship to the project

	No. of organisations
Contractors	8
Clients	8

Table 1.2

Project Cost (£m)

Project Cost (£m)	Client	Contractors	Total
under 1	1	-	1
1 - 5	3	-	3
5 - 25	2	5	7
over 25	2	3	5

Table 1.3

Project Duration

Project Duration	Client	Contractor	Total
under 6 mths.	1	-	1
6 mths.-1 yr.	-	-	-
1 yr.-3 yrs.	4	4	9
over 3 yrs.	3	3	6

Table 1.3.1.

Relationship/Correlation between Time & Cost

Cost/time	under 6 mths.	6 mths.- 1 year	1 year- 3 years	over 3 years
under 1	1			
1 - 5			3	
5 - 25			5	2
over 25			1	4

Table 1.4

Project Site

Project Site	Client	Contractor	Total
U.K.	6	4	10
Developed Country	1	2	3
Third World	1	2	3

Table 1.5

Location of the Project Manager during

	Design and procurement phase			Construction phase		
	Client	Contractor	Total	Client	Contractor	Total
Home office	8	5	13	7	2	9
Site	-	2	2	1	6	7

Table 1.6

To whom is the Project Manager responsible?

	Client	Contractor	Total
Project Director	4	5	9
Operations Director	1	2	3
Managing Director			
Project Group Manager & Steering Committee	1		1
Asst. Works Manager	1		1
Architect	1		1
Construction Engineer	1		1

Table 1.7

Temporary Staff employed on the project

	Client	Contractor	Total
Yes	6	5	11
No	2	3	5

Table 1.8

Reason for employing temporary staff

	Client	Contractor	Total
(a) Workload	1	2	3
(b) Unable to obtain permanent staff	3	0	3
(c) To obtain skills not existing within the organisation		1	1
(d) Fluctuating base level			
(a) & (b)		1	1
(b) & (c)	1	1	2
Not responded	3	3	6

Table 1.9

Efficiency of the temporary staff relative to equivalent permanent staff

	Client	Contractor	Total
Same	4	2	6
Better	0	1	1
Worse	2	2	4
Not responded	2	3	5

Table 2.1

Work breakdown structures in use

	Client	Contractor	Total
One	1	3	4
Two	1	2	3
Three	2	1	3
Over three	4	2	6

Table 2.2

Basis for the major work breakdown

		Client	Contractor	Total
(a)	Cost Codes	-	1	1
(b)	Physical Work Packages	5	4	9
(c)	Disciplines		1	1
(d)	Geographic Areas		1	1
	(a) & (c)	1		1
	(a) & (d)	1		1
	(a), (b) & (c)		1	1
Not responded		1		1

Table 2.3

Levels in the major work breakdown

	Client	Contractor	Total
One	2	1	3
Two	2	1	3
Three	-	-	-
Four	1	1	2
Over four	2	5	7
Not responded	1	-	1

Table 2.4

Cost control categories in each level

	Under 10			10 - 30			30 - 100			over 100		
	Clt.	Cnt.	Ttl.	Clt.	Cnt.	Ttl.	Clt.	Cnt.	Ttl.	Clt.	Cnt.	Ttl.
Level 1	2	4	6	1	1	2	1	-	1	1	-	1
Level 2	-	1	1	1	2	3	1	1	2	1	-	1
Level 3	-	1	1	-	-	-	1	2	3	1	-	1
Level 4				-	1	1	-	2	2	2	2	4

Table 2.5

At what level is there a link between the workdown structure, used for cost control, and that used for progress control?

	Client	Contractor	Total
Non	4	-	4
Summary	1	1	2
Intermediate	-	2	2
Detail	1	4	5
Not responded	2	1	3

Table 2.6

Are project commitment budgets made before cost commitments are entered into?

	Client	Contractor	Total
Always	6	6	12
Usually	1	-	1
Sometimes	-	-	-
Not responded	1	2	3

Table 3.1

Maximum number of activities on a single return

	Client	Contractor	Total
Under 100	-	-	-
100-500	1	2	3
500-1000	1	1	2
1000-5000	4	3	7
5000-10000	-	2	2
over 10000	-	-	-
not responded	2	-	2

Table 3.2

Levels in the project plan

	Client	Contractor	Total
One	3	1	4
Two	3	2	5
Three	-	2	2
Four	-	1	1
Over four	-	1	1
Not responded	3	-	3

Table 3.3

Update/Review period for progress

	Client	Contractor	Total
Daily	-	-	-
Weekly	-	-	-
Fortnightly	-	3	3
Monthly	7	5	12
Bimonthly	1	-	1
Quarterly			

Table 3.4

No. of activities at each level of the project plan in total

	Under 100			1 - 500			500 - 1,000			1,000 - 5,000			5,000 - 10,000		
	Clt.	Cnt.	Ttl.	Clt.	Cnt.	Ttl.	Clt.	Cnt.	Ttl.	Clt.	Cnt.	Ttl.	Clt.	Cnt.	Ttl.
Level 1	3	4	7		1	1				1		1			
Level 2				3	3	6		1	1	2	-	2	-	1	1
Level 3	-	1	1							-	2	2			
Level 4											1	1			
Lowest level							1		1						

Table 3.5

Maximum number of work packages for cost control

	Client	Contractor	Total
Under 100	4	3	7
100-500	1	3	4
500-1000	1	-	1
1000-5000	-	-	-
over 5000	-	-	-
Not responded	2	2	4

Table 3.6

Update Review Period for costs

	Client	Contractor	Total
Weekly	-	1	1
Fortnightly	-	1	1
Monthly	5	6	11
Quarterly	1	-	1
Not responded	2	-	2

Table 3.7

Time delay between the data cut-off and report issue for

	Cost Control			Progress Control		
	Client	Contr.	Total	Client	Contr.	Total
Under 3 days	-	-	-	1	1	2
3 days - 1 week	1	4	5	4	2	6
1 week - 2 weeks	-	3	3	-	3	3
2 weeks - 1 month	3	1	4	3	1	4
over 1 month	1	-	1	3	1	4
not responded	3	-	3	-	-	-

Table 4.1

Is the information used for updating time and costs

	Client	Contractor	Total
Independent	6	2	8
Related	1	5	6
Not responded	1	1	2

Table 4.2

How is update information obtained for

	Project network			Cost data		
	Client	Contr.	Total	Client	Contr.	Total
(a) Rev. meet.	1	2	3	2	2	4
(b) Prog. chas.	2	3	5	1	2	3
(c) Computer produced schedule	-	-	-	2	1	3
(d) Pro-forma return	-	3	3	-	3	3
(a) & (b)	5	-	5	1	-	1
Not respond.				2	-	2

Table 4.3

Are records kept of historical

	Progress information			Resource usage			Cost information		
	Client	Contr.	Total	Client	Contr.	Total	Client	Contr.	Total
Yes	5	6	11	6	5	11	7	7	14
No	2	2	4	2	2	4	1	-	1
Not. respond	1	-	1	1	-	1	1	-	1

Table 5.1

Planning Methods

	Do you use a computerised network			Do you use a computerised cost control system			Is it linked to a computerised network			Do you use a computerised procurement system			Is it linked to a computerised network		
	Client	Contr.	Total	Client	Contr.	Total	Client	Contr.	Total	Client	Contr.	Total	Client	Contr.	Total
Yes	5	7	12	8	6	14	-	3	3	3	1	4	-	-	-
No	3	1	4	-	2	2	7	5	12	5	7	12	6	6	12
Not resp.							1		1				2	2	4

Table 5.2

Is your achievement relative to

	Planned Dates			Budgeted Costs		
	Early	ontime	late	under budget	on budget	over budget
Client	-	3	5	1	2	5
Contr.	-	2	6	-	6	2
Total	-	5	11	1	8	7

Table 5.3

Use of Risk and Uncertainty

	PERT		ANY OTHER METHOD		
	Yes	No	Yes	No	Not responded
Client	-	8	1	6	1
Contr.	-	8	-	8	-
Total		16	1	14	1

Table 6.1

Computing

	Computer System			Configuration of the equipment		
	Inhouse	Bureau	Inhouse & Bureau	Mainframe	Mini	Main frame & mini
Client	6	-	2	6	1	1
Contr.	6	1	1	5	2	1
Total	12	1	3	11	3	2

Table 6.2

Input to the Computer

	Paper Tape	Terminals	Punch Cards	PT & T	PT & PC	T2 PC
Client	-	4	2	1	-	1
Contr.	-	6	-	1	1	-
Total	-	10	2	2	1	1

Table 6.3

Type of Program used

Purpose	Program type								
	Package			Developed in House			None		
	Client	Contr.	Ttl.	Client	Contr.	Ttl.	Client	Contr.	Ttl.
(a) Planning/ Networks	5	6	11	1	2	3	-	-	-
(b) Cost Cont.	-	2	2	4	3	7	1	1	2
(c) Materials Control	-	1	1	2	2	4	2	1	3

Table 6.4

Data processing support provided by

	Project team	DP Dept.	Bureau	Not responded
Client	2	5	-	1
Contractor	1	6	1	-
Total	3	11	1	1

Table 6.5

Formal training in the use of network/time control package

	Yes	No	Not resp.
Client	2	4	1
Contractor	8	1	-
Total	10	5	1

Table 6.6

Computer Program Chosen By

Purpose	Owner Policy			Contractor Policy			Project Manager		
	Clt.	Contr.	Ttl.	Clt.	Contr.	Ttl.	Clt.	Contr.	Ttl.
Planning/ Networks	4	2	6	-	6	6	-	2	2
Cost Control	3	2	5	-	3	3	-	-	-
Materials control	1	1	2	-	2	2	-	-	-
Not responded									

Table 7.1

Continuing Collaboration

	Yes	No
Client	3	5
Contractor	4	4
Total	7	9

Appendix D

Forecasting Techniques - Characteristics, Uses and Limitations

Appendix D

Forecasting Methods

In broad terms all forecasting techniques can be divided into two major categories :

(1) Qualitative or technological methods

(2) Quantitative techniques

(1) Qualitative techniques are generally used when data is not available, for example, when a product is first introduced into a market, or a new technology is introduced. This method usually requires intuitive thinking, human judgement and expert opinion to turn qualitative information into quantitative estimates. Techno logical methods fall into the two general categories of exploratory and normative character. Exploratory methods (such as Delphi, S-curves, analogies and morphological research) begin with the past and present as their starting point and move towards the future in a heuristic manner, often looking at all available possibilities. Normative methods (such as decision matrices, relevance trees, and system analysis) start with the future by determining future goals and objectives, then work backwards to see if these can be achieved, given the constraints, resources, and technologies available.

(2) Quantitative forecasting techniques fall into two types : naive or intuitive methods, and formal quantitative methods based on statistical principles.

The first type uses horizontal, seasonal, or trend extrapolation and is based on empirical experience that varies widely from one business, product or forecaster to another. Naive methods are simple and easy to use but not always as accurate as formal quantitative methods. Because of this limitation their use has been declining as formal methods have gained in popularity. Nevertheless, many organisations are still using them, either because they are not aware of other simpler methods, or because they prefer to use more subjective approaches to forecasting such as predicting this year's forecast as lat year's plus, say 10%.

Formal methods can also involve extrapolation, but it is done in a standard way using a systemmatic approach that attempts to minimize the forecasting errors. There are several formal methods that are inexpensive and easy to use that can be applied in a mechanical manner. These methods are useful when forecasts are needed for a large number of items and when forecasting errors on a single item will not be extremely costly.

Persons unfamiliar with quantitative forecasting methods often think that the past cannot describe the future accurately because everything is constantly changing. After some familiarity with data and forecasting techniques, however, it becomes clear that although nothing remains the same, history does repeat itself in a sense. Application of the right method can often identify the relationship between the factor to be forecasted and time itself (or several other factors), thus making accurate forecasting possible.

An alternative approach for classifying quantitative forecasting methods is to consider them as time series and regression (causal) methods. In time series models prediction of future is based on past values of a variable and/or past errors. The objective of these time series forecasting methods is to discover the pattern in the historical data series and extrapolate that pattern into the future.

Causal models on the other hand assume that the factor to be forecasted exhibits a cause-effect relationship with one or more independent variables. The purpose of the causal model is to discover the form of that relationship and use it to forecast future values of the dependent variable.

Both time series and causal models have advantages in certain situations. Time-series models can often be used more easily to forecast, whereas causal models can be used with greater success for policy and decision making. Whenever the necessary data are available, a forecasting relationship can be hypothesized, either as a function of time or as a function of independent variables, and tested.

An important step in selecting an appropriate time-series method is to consider the types of data pattern, so that the methods most appropriate to those patterns can be tested. Four types of data pattern can be distinguished : Long-term trend, cyclical, seasonal and irregular variations.

Many data series include combinations of the above patterns. Forecasting methods that are capable of distinguishing each of the patterns are employed if a separation of the component pattern is needed. Similarly, alternative methods of forecasting can be used to identify the pattern and to best fit the data so that future values can be forecasted.

To determine the basic pattern in the data, a number of steps may be taken. One is to plot the data. This approach may take considerable time and requires that the data be studied carefully to identify seasonality and other patterns. A better approach of determining the type of pattern in the data is the study of the autocorrelations. This approach will be examined later.

Time Series Analysis

Smoothing and decomposition time-series methods are frequently the most appealing and widely used techniques. Although both methods are somewhat weak in their statistical and mathematical rigor in their theoretical development, they have been accepted very well by practitioners who find them easy to use and fairly accurate for the costs involved.

Smoothing Methods

The basis of the smoothing methods is the sample weighting or smoothing of past observations in a time series in order to obtain a forecast for the future. In smoothing these historical values, random errors are averaged and such methods result in a "smooth" forecast that seems to work well in certain situations. The major advantages of smoothing methods are their low cost, the ease with which they can be applied, and the speed with which they can be adopted. These characteristics make them particularly attractive when a large number of items are to be forecasted, as is the case in many inventory systems. There is no doubt that better accuracy can usually be obtained using the more sophisticated methods of autoregressive/moving average schemes examined later.

There are a number of different smoothing methods such as Brown (1957), Holt (1956), Winters (1960), Brown & Meyer (1961). At least one of these is usually capable of dealing with any given data pattern when that basic pattern is known. If the pattern is not known, a general method such as Winter's, which can deal with a range of patterns is required. These methods are generally suitable for short term forecasting.

Decomposition Methods

The composition methods usually try to identify three separate components of the basic underlying pattern that tend to characterise economic and business series. These are the trend, the cycle, and the seasonal factors. The trend represents the long-run behaviour of the data, and can be increasing, decreasing or unchanged. The cyclical factor reporesents the ups and downs of the economy or of a specific industry. The seasonal factor relates to periodic fluctuations of constant length that are caused by such things as temperature, rainfall, month of the year, timing of holidays, etc. The distinction between seasonality and cyclicality is that seasonality repeats itself at fixed intervals such as a year, month, or week, while cyclical factors have a longer duration that varies from cycle to cycle.

Decomposition assumes that the data is made up as follows :

data = pattern + error

= f (trend, cycle, seasonality) + error.

From a statistical point of view there are a numcer of theoretical weaknesses in the decomposition approach. Practitioners, however, have largely ignored these weaknesses and have used the approach with considerable success.

Regression and Econometric Methods

The regression approach to forecasting is significantly different from that of time series in that it seeks to discover and measure relationships of several important factors and their effects on the variable to be forecast, and then to use them in obtaining forecasts. Regression analysis is a powerful method of estimation and the most commonly used causal approach to forecasting. It is quite flexible and can include any number of factors in the forecasting model.

Applying simple regression requires little statistical knowledge, limited data, and only moderate computational effort. (Most programmable calculators are adequate for the computations.) Multiple regression requires a much greater level of sophistication, considerably more data, and a computer to do the computations.

Simple regression is a special case of multiple regression, and the latter is a special case of econometric models. While multiple regression involves a single equation, econometric models can include any number of simultaneous multiple regression equations. The main advantage of econometric models lies in their ability to deal with interdependencies, but econometric models are considerably more difficult to develop and estimate. The difficulties are usually of two types :

1. technical aspects, involved in specifying the equations and estimating their parameters, and
2. cost considerations, related to the amount of data needed and the computing and human resources required.

One of the major weaknesses of econometric models is the absence of a set of rules that can be applied across different situations. This lack makes the development of econometric models highly dependent upon the specific situation and requires the involvement of a skilled and experienced econometrician. These disadvantages have limited the application of econometrics to forecasting in medium and small organizations.

Econometric models are difficult and costly to build and operate. They are generally aimed towards policy-making and their usefulness in forecasting is somewhat controversial . These characteristics have limited the development of econometric models by individual companies. However, econometric forecasts can be purchased through several services at economical rates.

Autoregressive/Moving Average (ARMA) Time-Series Methods

In earlier sections two major categories of time-series forecasting techniques smoothing and decomposition were examined. Smoothing methods base their forecasts on the principle of averaging (smoothing) past errors by adding a percentage of the error to a percentage of the previous forecast. Mathematically, single smoothing methods are of the form :

$$F_{t+1} = F_t = \alpha \ (X_t - F_t) \qquad (1)$$

Eq (1) can be expanded by substituting

$$F_t = F_{t-1} + \alpha \ (X_{t-1} - F_{t-1})$$

Thus,

$$F_{t+1} = F_{t-1} + \alpha \ (X_{t-1} - F_{t-1}) + \alpha \ (X_t - F_t) \qquad (2)$$

Substituting for F_{t-1} in the first term of (2) gives

$$F_{t+1} = F_{t-2} + \alpha \ (X_{t-2} - F_{t-2}) + \alpha \ (X_{t-1} - F_{t-1}) + \alpha \ (X_t - F_t) \qquad (3)$$

and so on, Given some initial forecast, say F_{t-2}, new forecasts can be obtained by adding a percentage of the errors between the actual and forecast values (e.g. $X_{t-2} - F_{t-2}$) to this initial forecast. Since some of the errors will be negative and some positive, the final forecast F_{t+1}, on average, will be close to the actual pattern of the data.

Time series decomposition methods are based on the principle of "breaking down" a time series into each of its components of seasonality, trend, cycle, and randomness and their forecasting by predicting each component separately (except randomness, which cannot be predicted) and recombining those predictions. Both smoothing and decomposition methods express their forecasts as a function of time only.

Another approach to forecasting, causal or explanatory methods, was discussed earlier. The three methods - linear, multiple regression and econometric are similar in concept, but differ in the level of sophistication they require. In their general form, regression methods attempt to forecast variations in some variable of interest, the dependent variable, based on variations in a number of other factors.

In multiple regression, the causal or explanatory model is of the form :

$$\hat{Y} = a + b_1 X1_1 + b_2 X_2 + \ldots\ldots + b_k X_k + U \qquad (4)$$

In eq (4), X1, X2, ..., X_k can represent any factors such as prices, money supply, GNP etc. suppose, however, that these variables are defined as

$$X_1 = Y_{t-1}, X_2 = Y_{t2}, X_3 = Y_{t-3}, \ldots\ldots X_k = Y_{t-k}$$

Eq (4) then becomes

$$Y_t = a + b_1 Y_{t-1} + b_2 Y_{t-2} + \ldots\ldots + b_k Y_{t-k} + U_t \qquad (5)$$

Eq (5) is still a regression equation, but differs from (4) in that the right-hand side variables of (4) are different independent factors, while those of (5) are previous values of the dependent variable Y_t. These are simply time-lagged values of the dependent variable, and therefore the name autoregression (AR) is used to describe equations or schemes of the form (5). By examining Eq (6) below, it can be seen that the method of single exponential smoothing has a form very similar to (5)

$$F_{t+1} = \alpha X_t + \alpha(1-\alpha) X_{t-1} + \alpha(1-\alpha)^2 X_{t-2} + \alpha(1-\alpha)^3 X_{t-3} + \ldots\ldots \quad (6)$$

In forecasting with exponential smoothing the past values are weighted by using the coefficients (parameters) α, $\alpha(1-\alpha)$. $\alpha(1-\alpha)^3$, ...

One question that arises from considering eq (5) is why regression that is applied to a time series (ie autoregression) should be treated differently from the regression used in causal models. The answer is twofold :

1. In autoregression the basic assumption of the independence of the residuals can be easily violated, since the independent variables of eq (5) usually depend upon each other.
2. Determining the number of past terms of Y_t to include in eq (5) is not an easy task.

For these reasons autoregression can be effectively coupled with moving average terms to form a very general and highly accurate class of time series models called autoregressive/moving average (ARMA) schemes of processes.

Identifying characteristics of a series such as stationarity, seasonality, etc., require a systematic approach. One such process is called time-series analysis and utilises the autocorrelation coefficients for different time lags of the variable to be forecast.

Autocorrelations

Eq (5) consists of a dependent variable, Y_t, and k right-hand side variables, Y_{t-1}, Y_{t-2}, ..., Y_{t-k} all of which are past values of the dependent variable. The simple correlations between Y_t and Y_{t-1}, can be found as described previously for regression. Since these correlations refer to the same (auto) variable, but of different time periods (lags), they are called autocorrelations. The autocorrelation of Y_t

and Y_{t-1} for example, indicate how variable Y_t and Y_{t-1} are related to each other.

The correlation of successive values of a random series would be close to zero. The autocorrelations of other time lags can be used to learn the following about the data :

1. Are the data random ?
2. Are the data stationary ?
3. If nonstationary, at what level do they become stationary ?
4. Are the data seasonal ?
5. If seasonal, what is the length of seasonality ?

The above chracteristics can be determined in a routine manner using autocorrelation analysis.

The Sampling Distribution of Autocorrelations

As shown by Anderson (1942), Bartlett (1949), Quenouille (1949), and others, the autocorrelation coefficients of random data have a sampling distribution that can be approximated by a normal curve with mean zero and standard error $1/\sqrt{n}$. This information can be used to develop tests of hypotheses similar to those of the F-test and the t-tests. These can be used to determine whether some r_k comes from a population whose value is zero at k time lags.

Existence of Stationarity : The autocorrelations of stationary data drop to zero after the second or third time lag, while for a non-stationary series they are significantly different from zero for several time periods.

Removing Nonstationarity Trends of any kind tend to introduce spurious autocorrelations that dominate the autocorrelation pattern. It is imperative, therefore, to remove the nonstationarity from the data before proceeding further with time-series analysis. Removing trends can be routinely achieved through the method of <u>differencing</u>. Usually stationarity is achieved by taking differences between successive values of the time series. If the autocorrelations of the first differenced data do not drop to zero after the second or third lag, it indicates that stationarity has not yet been achieved and therefore first differences of the first differenced data should be taken. In practice, it is seldom necessary to go beyond second differences, because real data generally involves nonstationaries of only the first or second level.

Recognizing Seasonality

Seasonality is defined as a pattern that repeats itself over fixed intervals of time.

For stationary data, seasonality can be found by identifying those autocorrelation coefficients of more than two or three time lags that are significantly different from zero. Any autocorrelation that is significantly different from zero implies the existance of a pattern in the data. To recognize seasomlity, one must look for such high autocorrelations.

The X^2-Test

Box and Pierce (1970) have developed a test (known as the Box-Pierce Q-Statistic) that is capable of determining whether several autocorrelation coefficients are significantly different from zero. This test is based on the X^2 (Chi-squared) distribution of the auto-correlation coefficients. If the computed value of the test is less than that from the table of values of the χ^2 statistic, the autocorrelations are significantly different from zero, indicating the existence of some pattern.

The Q-statistic is computed as

$$\chi^2\text{-test} = n \sum_{k=1}^{m} r_k^2 ,$$

where m is the largest time lag included.
The smaller the autocorrelations, the smaller the value of χ^2.
This χ^2-test also holds true when applied to the autocorrelations of residual errors.

Partial Autocorrelations

Partial autocorrelations are used to measure the degree of association between X_t and X_{t-g} when the effect of other time lags on X is held constant. Their singular purpose in time-series analysis is to help identify an appropriate ARMA model for forecasting. (In fact, they have been constructed just for this use).

When there are only p partial autocorrelations that are significantly different from zero, the process is assumed to be an AR(p). When the partial autocorrelations tail off to zero exponentially, the process is assumed to be an MA one.

Appendix E

Maximum Likelihood Estimation (MLE) of Parameters of some Distributions.

Kolmogorov-Smirnov Test

Appendix E

Maximum likelihood estimation (MLE) of parameters of some distributions.

Weibull Distribution

The probability density function of the Weibull distribution is given by

$$f(t) = \frac{cb^{c-1}}{b^c} \exp[-(x|b)^c], \; t > 0, \; b > 0, \; c > 0 \qquad (\;.1)$$

where b and c are called scale and shape parameters, respectively.

Let $\frac{1}{b^c} = \alpha$ so that Eq. (1) can be written as

$$f(t) = c\,\alpha\, t^{c-1} \exp(-\alpha t^c) \;. \qquad (\;2)$$

Let t_i, i = 1, ... n be the observations, where n is the size of the sample. The likelihood function of the above observatious can be written as

$$L = \prod_{i=1}^{n} f(t_i) \qquad (\;3)$$

or

$$\mathcal{L} = \ln L = \sum_{i=1}^{n} \ln [c\,\alpha\, t_i^{c-1} \exp(-\alpha t_i^c)]$$

$$= n \ln c + n \ln \alpha + (c-1) \sum_{i=1}^{n} \ln t_i - \alpha \sum_{i=1}^{n} t_i^c \;. \qquad (\;4)$$

Then $$\frac{\partial \mathcal{L}}{\partial \alpha} = \frac{n}{\alpha} - \sum_{i=1} t_i^c \qquad (\;5)$$

and $$\frac{\partial \mathcal{L}}{\partial c} = \frac{n}{c} + \sum_{i=1}^{n} \ln t_i - \alpha \sum_{i=1}^{n} (t_i^c \ln t_i) \qquad (\;6)$$

Putting equation (5) equal to zero.

$$\hat{\alpha} = \frac{n}{\sum_{i=1}^{n} t_i^c} \qquad (7)$$

Substituting (7) in (6) for and equating the result to zero, we obtain

$$\frac{n}{\hat{c}} + \sum_{i=1}^{n} \ln t_i - \frac{n}{\sum_{i=1}^{n} t_i^{\hat{c}}} \left[\sum_{i=1}^{n} (t_i^{\hat{c}} \ln t_i) \right] = 0 \qquad (8)$$

The above equation can be solved numerically for c, using an iterative method such as Newton-Raphson.

Normal Distribution

The probability density function of the normal distribution is given by

$$f(t) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left\{- \frac{1}{2\sigma^2} (t - \mu)^2\right\}, \quad -\infty < t < \infty,$$
$$-\infty < \mu < \infty,$$
$$\sigma > 0 \qquad (1)$$

where μ and σ are the mean and standard deviation of the distribution.

Let t_i , $i = 1, \dots n$ be a sample of size n. The likelihood function of the above observations can be written as:

$$L = \prod_{i=1}^{n} f(t_i) \qquad (2)$$

or

$$\mathcal{L} = \ln L = \sum_{i=1}^{n} \ln f(t_i)$$

$$= \sum_{i=1}^{n} \ln \left[\frac{1}{\sqrt{2\pi}\sigma} \exp\left\{- \frac{1}{2\sigma^2} (t_i - \mu)\right\}\right]$$

$$= - \frac{n}{2} \ln (2\pi) - n \ln \sigma - \frac{1}{2\sigma^2} \sum_{i=1}^{n} (t_i - \mu)^2 \qquad (3)$$

Then

$$\frac{\partial \mathcal{L}}{\partial \mu} = \frac{1}{\sigma^2}\left[\sum_{i=1}^{n} t_i - n\,\mu\right] \qquad (4)$$

and

$$\frac{\partial \mathcal{L}}{\partial \sigma} = \frac{1}{\sigma^3}\left[n\,\sigma^2 - \sum_{i=1}^{n} (t_i - \mu)^2\right] . \qquad (5)$$

Equation (4) to zero, we obtain

$$\hat{\mu} = \frac{1}{n}\sum_{i=1}^{n} t_i = \bar{t} \qquad . \qquad (6)$$

Substituting (6) in (5) for and equating the result to zero, we obtain

$$\hat{\sigma}^2 = \frac{1}{n}\sum_{i=1}^{n} (t_i - \bar{t})^2 . \qquad (7)$$

However $\hat{\sigma}^2$ is a biased estimate of the variance. To obtain an unbiased estimate for variance the denominator in equation (7) should be changed to $(n - 1)$.

Lognormal Distribution

The probability density function of the lognormal distribution can be written as:

$$f(t) = \frac{1}{\sqrt{2\pi}\,\beta t}\exp\left[-\frac{1}{2\beta^2}(\ln t - \delta)^2\right], \quad t > 0, \quad \beta > 0,$$
$$-\infty < \delta < \infty \qquad (1)$$

where δ and β respectively are the scale and shape parameters of the distribution.

Let t, $i = 1, 2, \ldots n$ be a sample of size n, the likelihood function of the observations can be written as

$$L = \prod_{i=1}^{n} f(t_i) \qquad (2)$$

or

$$\mathcal{L} = \ell n\, L = \sum_{i=1}^{n} \ell n\, f(t_i)$$

$$= \sum_{i=1}^{n} \ell n \left[\frac{1}{\sqrt{2\pi}\beta t_i} \exp\left\{ -\frac{1}{2\beta^2} (\ell n\, t_i - \delta)^2 \right\} \right]$$

$$= -\frac{n}{2} \ell n\, (2\pi) - n\, \ell n\, \beta - \sum_{i=1}^{n} \ell n\, t - \frac{1}{2\beta^2} \sum_{i=1}^{n} (\ell n\, t_i - \delta)^2 . \qquad (3)$$

Then

$$\frac{\partial \mathcal{L}}{\partial \delta} = -\frac{1}{\beta^2} \sum_{i=1}^{n} (\ell n\, t_i - \delta) \qquad (4)$$

and

$$\frac{\partial \mathcal{L}}{\partial \beta} = -\frac{n}{\beta} + \frac{1}{\beta^3} \sum_{i=1}^{n} (\ell n\, t_i - \delta)^2 \qquad (5)$$

Putting equations (4) and (5) equal to zero, we obtain

$$\sum_{i=1}^{n} (\ell n\, t_i - \hat{\delta}) = 0 \qquad (6)$$

and

$$-n\, \hat{\beta}^2 + \sum_{i=1}^{n} (\ell n\, t_i - \hat{\delta})^2 = 0 \qquad (7)$$

or

$$\hat{\delta} = \frac{1}{n} \sum_{i=1}^{n} \ell n\, t_i \qquad (8)$$

and

$$\hat{\beta}^2 = \frac{1}{n} \sum_{i=1}^{n} (\ell n\, t_i - \hat{\delta})^2 \qquad (9)$$

Gamma Distribution

The probability function of the gamma distribuion is given by

$$f(t) = \frac{\alpha^k \; t^{k-1} \; e^{-\alpha t}}{\Gamma(k)} \quad t > 0, \alpha > 0, k > 0 \qquad (\ 1)$$

where α and k are called the sacle and shape perameters, respectively.

Let t_i, i = 1, ... n be a sample of size n. The likelihood function of the above observations is given by

$$L = \prod_{i=1}^{n} f(t_i) \qquad (\ 2)$$

or

$$= \ell n\ L = \sum_{i=1}^{n} \ell n\ f(t_i)$$

$$= \sum_{i=1}^{n} \left[\ell n \frac{\alpha^k \; t_i^{k-1} \; e^{-\alpha t_i}}{\Gamma(k)} \right]$$

$$= n\ k\ \ell n\ \alpha - n\ \ell n\ \Gamma(k) + (k-1) \sum_{i=1}^{n} \ell n\ t_i - \alpha \sum_{i=1}^{n} t_i \qquad (\ 3)$$

Then

$$\frac{\partial \mathcal{L}}{\partial \alpha} = \frac{nk}{\alpha} - \sum_{i=1}^{n} t_i \qquad (\ 4)$$

and

$$\frac{\partial \mathcal{L}}{\partial k} = n\ \ell n\ \alpha - n\ \psi\ (k) + \sum_{i=1}^{n} \ell n\ _i \qquad (\ 5)$$

where

$$\psi(k) = \frac{\partial\ \ell n\ \Gamma(k)}{\partial k}$$

Equating equation (4) to zero, we obtain

$$\hat{\alpha} = \frac{\hat{k}}{\mu} \qquad (\ 6)$$

where

$$\mu = \frac{1}{n} \sum_{i=1}^{n} t_i \quad .$$

Substituting (6) in (5) and equating the result to zero, one obtains

$$n \ln \hat{k} - n \ln \mu + \sum_{i=1}^{n} \ln t_i - n \psi(\hat{k}) = 0 \qquad (7)$$

or

$$\ln \hat{k} - \psi(k) = \ln \mu - \ln G \qquad (8)$$

where $G = \sqrt[n]{\prod_{i=1}^{n} t_i}$ is the geometirc mean of the observed values . An approximate method for determing k is to use the asymptotic expansion of $\psi(k)$ given by

$$\psi(\hat{k}) = \ln \hat{k} - \frac{1}{2\hat{k}} + \frac{1}{12\,\hat{k}^2} + \ldots \qquad (9)$$

This gives:

$$\frac{1}{2\hat{k}} + \frac{1}{12\hat{k}^2} \approx \ln \mu - \ln G \qquad (10)$$

Solving (10) for $\hat{k}$, we obtain:

$$\hat{k} = \frac{1}{4(\ln \mu - \ln G)} \left[1 + \sqrt{1 + \frac{4(\ln \mu - \ln G)}{3}}\right] \qquad (11)$$

More comprehensive treatment on above can be found in Kendall and Stuart (1958) and Greenwood and Durnad (1960).

Kolmogorov-Smirnov Statistics

Table .. Percentage Points of the Kolmogorov-Smirnov Statistic

Sample size (N)	Level of significance for D = maximum $\lvert F_0(X) - S_r(X)\rvert$				
	.20	.15	.10	.05	.01
1	.900	.925	.950	.975	.995
2	.684	.726	.776	.842	.929
3	.565	.597	.642	.708	.828
4	.494	.525	.564	.624	.733
5	.446	.474	.510	.565	.669
6	.410	.436	.470	.521	.618
7	.381	.405	.438	.486	.577
8	.358	.381	.411	.457	.543
9	.339	.360	.388	.432	.514
10	.322	.342	.368	.410	.490
11	.307	.326	.352	.391	.468
12	.295	.313	.338	.375	.450
13	.284	.302	.325	.361	.433
14	.274	.292	.314	.349	.418
15	.266	283	.304	.338	.404
16	.258	.274	.295	.328	.392
17	.250	.266	.286	.318	.381
18	.244	.259	.278	.309	.371
19	.237	.252	.272	.301	.363
20	.231	.246	.264	.294	.356
25	.21	.22	.24	.27	.32
30	.19	.20	.22	.24	.29
35	.18	.19	.21	.23	.27
Over 35	$\frac{1.07}{\sqrt{N}}$	$\frac{1.14}{\sqrt{N}}$	$\frac{1.22}{\sqrt{N}}$	$\frac{1.36}{\sqrt{N}}$	$\frac{1.63}{\sqrt{N}}$

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